The Influence of the Mineral Nature and the Temperature of the Aggregate in the Water Resistance of Foam Bitumen Stabilized Mixes

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ABSTRACT: In-place foamed bitumen stabilization is experiencing a global growth worldwide. This pavement rehabilitation process was introduced in Canada in the early nineties. It is currently estimated that between two and three million square metres of pavement are rehabilitated using this method every year throughout Canada. The driving engine of in-place stabilization is associated with the concept that the existing pavement is the source of primary materials to create a new pavement material. The existing pavement materials are reclaimed and transformed into a sized material, which is then mixed with a foamed bitumen binder and laid down in-place. Foamed stabilized mixtures have properties that differ significantly from those of standard hot bituminous mixtures. Contrary to hot bituminous mixes, the coating of the aggregate is selective and the voids in the mixture are high. Consequently, properties of foam-stabilized mixtures are closely associated with the aggregate skeleton of the mixture. In general, foam mixes are not as thermal sensitive as hot mix and their resistance to rutting and thermal cracking is excellent. However, the cohesion of foam mixes is significantly lower than hot mix which reduces their resistance to water damage. This paper focuses on the water resistance of in-place foamed bitumen stabilized mixes that have between 2.5 and 3.0 % added binder. The concepts associated with water resistance in relation to the temperature of the aggregate during mixing and the mineral nature/gradation of the aggregate are outlined. And finally, the paper provides results of testing of mixes produced using various water resistance enhancers.

KEY WORDS: Foam, stabilization, rehabilitation, stripping, pulverization

1 INTRODUCTION

The use of bitumen foam to stabilize granular and granular-hot mix blends has been around since the early 1960's. The process has undergone a number of changes over the years as the foaming equipment improved and the people involved developed a better understanding of the foaming process. The method of designing the finished product has made great strides in recent years. Wirtgen GMbH group from Germany in conjunction with A.A. Loudon and Partners of South Africa have published an excellent manual on cold recycling, which covers the design aspects of the foamed bitumen treated materials as well as the other methods of stabilization such as bituminous emulsion and Portland cement (Wirtgen, 2004).

Mixtures, which have been stabilized using the foam process, have physical properties that are much different than bituminous hot mix. In the foam process the mixtures are held together by the spot welding of the foamed bitumen to the aggregate or recycled asphalt/aggregate blend. In this process the mixture is selectively coated and the air voids in the mix are much higher than your typical hot mix. The air voids in foam mixes are typically in the range of 12 to 15 percent versus hot mix at 3.0 to 6.0 percent. This combination of high air voids and selective coating of the materials being foamed causes the physical properties to be more closely associated with the aggregate makeup. This structure tends to have less cohesion and this reduction in cohesion causes the foamed mixture to be more sensitive to moisture damage.

The focus of this paper is on the water resistance of in-place foamed bitumen stabilized mixes that have been designed with 2.5% added binder. Various filler additives have been used to improve water resistance. Bitumen emulsions were also used to replace the foamed bitumen to see what effects the use of bituminous emulsions has on moisture damage (Favretti et al, 1997). Also liquid anti-strips were tried as well as warming the material prior to foaming.

2 LABORATORY PROTOCOLS

The laboratory study involved the preparation and testing of nine different mixtures. The same mix proportions were used in all nine designs with a blend of 55% recycled asphalt pavement (RAP) and 45% in-place granular material. One point to be made regarding the test data is that the control mix was used in an actual project. Table 1 shows the gradation data for the mix used in the study.

Table 1: Gradations and Job Mix Formula for foam mixture study

Sieve	RAP Material	In-Place Granular	55/45 Blend
26.5 mm		100	100.
19.0 mm		99.0	99.6
16.0 mm	100	92.6	96.7
13.2 mm	95.3	87.5	91.8
9.5 mm	87.5	79.3	83.8
4.75 mm	63.6	65.0	64.2
2.36 mm	55.7	56.0	55.8
1.18 mm	49.8	45.4	47.8
0.600 mm	40.1	32.4	36.6
0.300 mm	27.2	19.6	23.8
0.150 mm	14.8	11.0	13.1
0.075 mm	7.9	6.6	7.3
% AC	5.04		
Total AC in Mix			5.26

The mixes all used a PG 58-28 bitumen that is used in the Province of Ontario as the base stock. The bitumen emulsion used for two of the mixes was produced using this same PG 58-28. The foam mixes were produced in a Wirtgen WLB 10 lab foaming unit using 2.5% PG 58-28 at 160ºC and having 3.0% water added to the PGAC to create the foam. The aggregate/RAP blend had 5.5% free water added prior to the foaming process. The emulsion mixes used 3.9% emulsion, which translated into 2.5% bitumen added. The pre-wet water was reduced by the amount of water in the emulsion. The description of the nine mixes produced, are as noted in Table 2.

All the nine mixes were compacted and cured using the design procedure from the Wirtgen cold mix manual (Wirtgen, 2004). The briquettes were compacted using 75 blows per side, cured overnight in the mould and then further cured in a forced air oven for 72 hours at 60ºC. The indirect tensile testing as well as Marshall stability testing was done at 25ºC.

Table 2: Description of nine mixtures used in study

Mix	Description
1	Control Mix – PG 58-28
2	PG 58-28 + 1.0% Portland Cement
3	PG 58-28 + 1.0% Hydrated Lime
4	PG 58-28 + 1.0% Lime Kiln Dust
5	CSS-1h emulsion (64% Residue)
6	CSS-1h + 1.0% Portland Cement
7	PG 58-28 – Mix warmed to 70ºC
8	PG 58-28 + 0.5% Anti-strip
9	PG 58-28 – Free Water + Anti-strip

3 DATA ANALYSIS

The test data obtained in the laboratory will be discussed in three sections; filler type additives, bitumen emulsions and other additives and techniques.

3.1 Filler Type Additives

The three different fillers were added to the aggregate blend prior to the pre-wetting process. The quantity used was 1.0% based on total weight of mix as it was felt that this percentage was fairly typical of what was being used in the industry. After foaming, compaction and curing the nine briquettes produced for each mix we divided into three sets of three for Marshall stability testing and wet and dry indirect tensile strength testing. The data obtained is as shown in Table 3.

The addition of the fillers has greatly improved the wet tensile strength of the mixtures and in doing so has improved the retained tensile strength by 20 to 35%. As would be expected the addition of the Portland cement has raised the Marshall stability as well as the improved wet strengths. Both the hydrated lime and the lime kiln dust have improved the retained strength giving the mixtures greater resistance to moisture damage as noted in other reported research (Thériault, 1998, Bowering et al, 1976).

Table 3: Foaming data using filler type additives

Mix	1	2	3	4	Specification
Process	Foaming				
Binder	PG 58-28	PG 58-28	PG 58-28	PG 58-28	
Percentage	2.5	2.5	2.5	2.5	
Additive	None	Portland Cement	Hydrated Lime	Lime Kiln Dust	
Percentage		1.0	1.0	1.0	
Test Data					
Bulk Relative Density	2.125	2.135	2.135	2.199	
Maximum Relative Density	2.487	2.483	2.484	2.482	
% Air Voids	14.6	14.0	14.1	14.6	
ITS – Dry (kPa)	404.2	377.7	370.6	360.5	300 min
ITS – Wet (kPa)	267.7	297.5	329.7	312.2	150 min
Retained ITS (%)	66.2	78.8	89.0	86.6	50% min
Marshall Stability (Newtons)	18659	20997	18955	16886	
Flow Index (0.25 mm)	14.2	14.7	15.7	15.8	

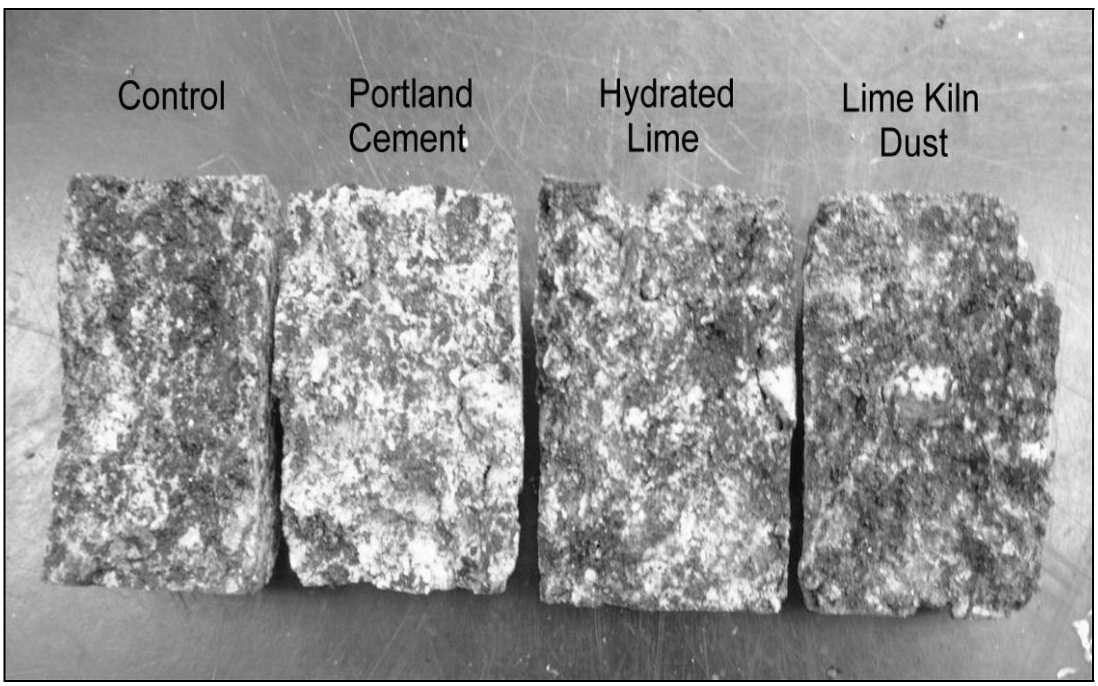

Figure 1: Photo showing coating of foam mixtures with filler additives

The photograph (Figure 1) shows the spot welding of the bitumen to the aggregate particles. The material is only partially coated and this would contribute to the lower retained strengths and concern about moisture damage. The photo of the lime kiln dust briquette shows that the dust is aiding the coating of the granular particles.

3.2 Bitumen Emulsion Mixtures

The two mixes were produced using 3.9% CSS-1h emulsion. This percentage translated into 2.5% residual bitumen to be equal to the bitumen foam mixtures. The quantity of added water was reduced by the amount present in the emulsion to keep all quantities of the ingredients the same. The Portland cement was added to the mixture in powdered form. The two mixtures were compacted, cured and tested the same way as the other seven foam mixes following the guidelines of the Wirtgen manual.

The usage of bitumen emulsion tends to give better compaction results as shown in Table 4. Both mixes have higher density numbers and also give much stronger wet strength values. The combination of the free water with the bituminous emulsion provides better dispersion of the bitumen throughout the mix, which in turn lubricates the mixture to allow for better compaction. The addition of the Portland cement gives better dry and wet strength numbers than the straight CSS-1h. The retained tensile strengths are much higher than the control mixture and comparing their values to Table 2 the emulsion mixtures give higher retained strengths than all the filler mixtures. The surfactant in the emulsion is also acting as an anti-strip agent and contributes to the improved strength index.

Table 4: Test data using bitumen emulsion

Mix	1	3	5	6	Specification
Process	Foaming		Emulsion		
Binder	PG 58-28	PG 58-28	CSS-1h	CSS-1h	
Percentage	2.5		3.9	3.9	
Additive	None	Hydrated Lime	None	Portland Cement	
Percentage				1.0	
Test Data					
Bulk Relative Density	2.125	2.135	2.144	2.157	
Maximum Relative Density	2.487	2.484	2.488	2.490	
% Air Voids	14.6	14.1	13.8	13.4	
ITS – Dry (kPa)	404.2	370.6	351.7	365.8	300 min
ITS – Wet (kPa)	267.7	329.7	321.1	419.8	150 min
Retained ITS (%)	66.2	89.0	91.3	114.8	50% min
Marshall Stability (Newtons)	18659	18955	14495	16775	
Flow Index (0.25 mm)	14.2	15.7	18.8	14.8	

The emulsion mixtures have much better coating than the control foam mixture as shown in Figure 2. The bituminous emulsion mixes are 100% coated and this has a positive contribution to the improved moisture damage resistance. As mentioned earlier the well-dispersed emulsion creates the excellent coating seen in the emulsion mixes. The warm mix will be discussed in the next section.

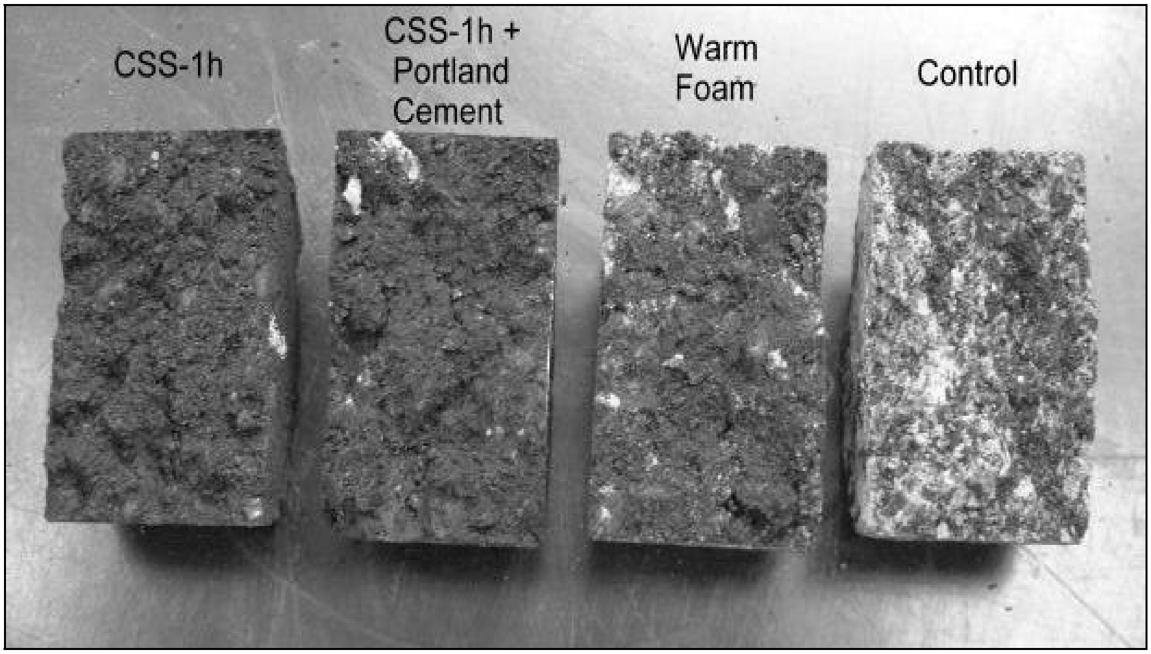

Figure 2: Photo showing coating of mixtures made with bituminous emulsions

3.3 Liquid Additives and Other Techniques

This section will be discussed in two parts; warm foam and anti-strip foam.

3.3.1 Warm Foam

The coating of the aggregate particles in a mix has an influence on the physical properties of that mix such as durability, moisture damage and overall strength of the mixture. In a foam mixture where the droplets of bitumen are spot-welded these welds are what provide the tensile strength to the mix. As in conventional hot mix the temperature of the mixture can have a large influence on the coating (Jenkins et al, 1999). The hotter the mix the easier it is to coat the aggregate particles and create a more uniform bitumen film. If a better and more even distribution of the bitumen can be achieved the overall properties of the finished mix should be improved. If this applies to hot mix it would be expected that the same principles should apply with a foamed mix that has been elevated in temperature.

The laboratory study included one of the nine mixes to be produced at an elevated temperature. To produce the warm mix the aggregate/RAP blend including the free water was heated to 70ºC prior to foaming with the PG 58-28. The finished material was then compacted, cured and tested the same way as the other eight mixes. The test results obtained on the warm foam mix are shown in Table 5 (Mix #7).

The density of the warm mix is much higher than the control mix, which would be due to the elevated compaction temperature. The wet strength has also increased compared to the control foam mix. The dry strength has decreased but overall the retained tensile strength has increased significantly. The higher temperature in the presence of the warm water has aided the dispersion of the foamed bitumen particles to greatly increase the coating of the mix particles. Figure 3 shows the coating of the mix compared to the control mix.

Table 5: Foaming data using other additives and techniques

Mix	1	7	8	9	Specification
Process	Foaming				
Binder	PG 58-28	PG 58-28	PG 58-28	PG 58-28	
Percentage	2.5	2.5	2.5	2.5	
Additive	None	Warmed to 70ºC prior to foaming	Liquid Antistrip added to PGAC	Liquid Antistrip added to free water	
Percentage			0.5	0.5	
Test Data					
Bulk Relative Density	2.125	2.176	2.120	2.120	
Maximum Relative Density	2.487	2.496	2.487	2.488	
% Air Voids	14.6	12.8	14.7	14.8	
ITS – Dry (kPa)	404.2	342.6	288.9	316.9	300 min
ITS – Wet (kPa)	267.7	361.1	359.7	375.2	150 min
Retained ITS (%)	66.2	105.3	124.3	118.4	50% min
Marshall Stability (Newtons)	18659	15420	14341	15023	
Flow Index (0.25 mm)	14.2	17.2	16.0	19.0	

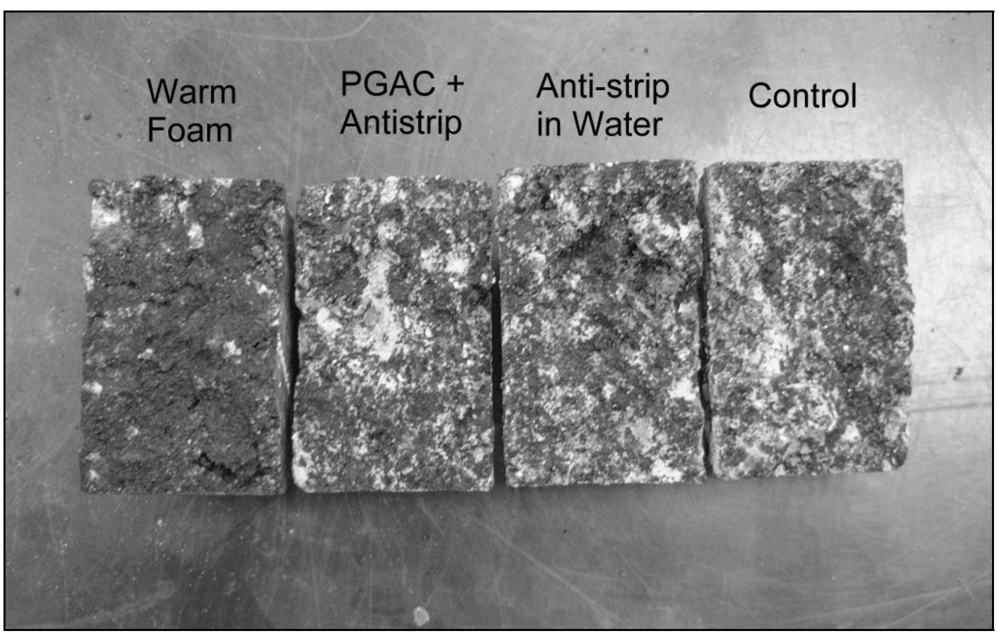

Figure 3: Photo showing coating of foamed mixtures made with liquid additives

3.3.2 Foaming with Anti-strip Agents

The use of surface-active agents has improved the resistance to moisture damage in hot mix for many years and the principles behind the process should apply to foam mixes. Other research has shown that these agents can improve the resistance and the laboratory study conducted by McAsphalt investigated this theory (Bowering et al, 1976). A mix was foamed using the PG 58-28 containing an anti-stripping agent at a level of 0.5%. The dosage level used is a typical level used in most hot mixes that require the use of an anti-stripping agent. The mix was foamed at the same temperature, compacted, cured and tested as the other mixes.

The second mix also used an anti-stripping agent in the mixture process. In this case the anti-stripping agent was mixed into the free water and then the water was added to the aggregate blend prior to being foamed with the PG 58-28. This mix was also foamed at the same temperature, compacted, cured and tested as the other mixes. The test data obtained on these two mixes is as shown in Table 5.

In comparison to the control mix the wet tensile strengths for both mixes have increased significantly with a drop in the dry strengths. The wet tensile strength for the mix made with the anti-strip in the water phase is higher than the other anti-strip mix. This is most likely due to the better dispersion of the anti-strip agent throughout the mixture compared to the foam mix made with the straight PG 58-28 or with the PG 58-28 containing the anti-strip agent. The dry tensile strength value for the foam mix made with the anti-stripping agent in the PG 58-28 has decreased to below the minimum specification of 300 kPa but this could be due to experimental variability in the test method. The overall percent retained strength shows that the addition of the anti-stripping agents does significantly improve the resistance to moisture damage. The density of both the mixes are the same as the control mix and much less than the mix produced warm. This would be expected as the PG bitumen is basically the same and the compaction temperatures are also the same. The photograph of the mixes (Figure 3) shows a slight improvement in the coating of the particles but not a significant amount that one could say that the use of anti-stripping agents will improve coating in foam mixes.

4 CONCLUSIONS

The very limited laboratory study has shown a number of positive conclusions that help to improve the foam stabilization process. Field experience over the last few years has confirmed a number of the findings determined in this brief laboratory study.

One point to be made regarding the test data is that the control mix was used in an actual project. The other eight mixes were designed to have the same residual bitumen as the control. These eight mixes may very well have had even better results if they had been designed for the optimum physical properties.

1. The use of filler additives such as Portland cement, hydrated lime and lime kiln dust improve the stripping resistance of the foamed mixtures and give increased wet strength. There also appears to be a slight improvement in the dispersion of the bitumen droplets of the foam mix giving better coating.
2. The use of the proper bituminous emulsion with and without Portland cement gives significant improvements in wet strength, moisture damage resistance and increased

compaction levels. The use of Portland cement with emulsion gives significant improvements to all physical properties. The bituminous emulsion also gives significant improvement in the coating of both the fine and coarse particles.

3. Pre-warming of the aggregate blend prior to foaming increases the wet strength and the density level of the foamed mix. The foam mix particles are much better coated than with traditional foam mixes.
4. The use of surface-active agents incorporated into the bitumen or into the free water prior to foaming increases the wet strength of the foamed material in a positive manner.

5 AKNOWLEDGEMENT

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