Fix It First: Utilizing the Seismic Property Analyzer and MMLS to Develop Guidelines for the Use of Polymer Modified Thin Lift HMA vs. Surface Treatments

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16. Abstract

The main objective of this study was to develop thin lift overlay mixtures with polymer modified asphalt for use in New England. As part of this research a comprehensive literature review and internet survey was conducted. Moreover, laboratory testing was conducted to develop thin lift Polymer Modified Asphalt (PMA) mixtures in an effort to evaluate their use for New England.

It was attempted to use the Model Mobile Load Simulator (MMLS) to investigate the feasibility of using a non-destructive testing (Potable Seismic Property Analyzer) to evaluate the thin lift mixtures. However, after several attempts to compact the asphalt mixtures in the device, achieving target density was not attainable. Accordingly this thin lift mixture testing was replaced by dynamic modulus testing in the Asphalt Mixture Performance Tester and low temperature cracking using the Indirect Tensile Test (IDT).

The survey conducted showed the method of selection for either a surface treatment or lift HMA overlay were decision trees, functional classification of the roadway, existing pavement condition, experience and treatment cost. Moreover, the majority of respondents did not have a methodology to select the appropriate time to apply a strategy. Based on the survey, transportation agencies utilized PMA to reduced cracking, reduce rutting, reduce thermal cracking, and extended pavement life. No disadvantages of using polymer modified asphalt were noted.

Thin lift mixtures were developed with five modified binders and one conventional binder for comparison purposes. The laboratory data indicated that the low temperature performance grade of the binders were warmer than the low temperature cracking of the mixtures predicted using IDT measurements. This indicates that the use of the PMA did not increase the low temperature susceptibility of the mixtures tested. Therefore, PMA could be utilized for thin lift mixtures placed in the New England region.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	mililitres	mL
gal	gallons	3.785	Litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

* SI is the symbol for the International System of Measurement

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C+32	Fahrenheit temperature	°F

°F 32 98.6 212 °F
-40 0 40 80 120 180 200
-40 -20 0 20 40 60 80 100
°C 37 °C

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List of Acronyms

AASHTO = American Association of State Highway and Transportation Officials
AEMA = Asphalt Emulsions Manufacturers Association
AMPT = Asphalt Mixture Performance Test
APA = Asphalt Pavement Analyzer
ASCE = American Society of Civil Engineers
CMCR = Chemically Modified Crumb Rubber
DOT = Department of Transportation
|E*| = Complex Dynamic Modulus
ESALs = Equivalent Single Axles Loads
EVA = Ethylene Vinyl Acetate
FHWA = Federal Highway Administration
FP^2 = Foundation for Pavement Preservation
FTT = Flexural Tension Tester
FWD = Falling Weight Deflectometer
GPR = Ground Penetrating Radar
GTR = Ground Tire Rubber
HMA = Hot Mix Asphalt
HWTD = Hamburg Wheel Tracking Device
IDT = Indirect Tensile Test
IRI = International Roughness Index
ISSA = International Slurry Surfacing Association
LCAA = Life Cycle Cost Analysis
LWT = Loaded Wheel Tester
MMLS = Model Mobile Load Simulator
NAPA = National Asphalt Pavement Association
NCAT = National Center for Asphalt Technology
NCHRP = National Cooperative Highway Research Program
NDT = Non Destructive Testing
NECEPT = Northeast Center for Excellence in Pavement Technology
NMAS = Nominal Maximum Aggregate Size
OGFC = Open Graded Friction Course
PG = Performance Grade
PM = Preventative Maintenance
PMA = Polymer Modified Asphalt
PMS = Pavement Management System
PPA = Poly Phosphoric Acid
PSPA = Portable Seismic Property Analyzer
PVC = Polyvinyl Chloride
QA = Quality Assurance
QC = Quality Control
RMA = Rubber Modified Asphalt
SBR = Styrene Butadiene Rubber

SBS = Styrene-Butadiene-Styrene
SGC = Superpave Gyratory Compactor
SMA = Stone Matrix Asphalt
SPA = Seismic Property Analyzer
VFA = Voids Filled with Asphalt
VMA = Voids in Mineral Aggregate
WTAT = Wet Track Abrasion Test

1.0 Introduction

Currently many of the New England states are adopting the "Fix it First" approach when faced with decisions to construct new pavement systems versus rehabilitating the existing pavement. This approach has been further backed by many of the state legislators who have allocated funds earmarked for "Fix it First" projects.

"Fix it First" pavement projects require the critical decisions regarding selection of an appropriate rehabilitation technique and the timing of its application. In New England little guidance exists to address these questions, rather the accepted practice is to resurface the existing pavement with surface treatments like Nova Chip and Micro Surfacing or replace the roadway entirely. This practice may lead to over or under rehabilitating critical roadways, which thus leads to extra funds being expelled in scenarios where it is not warranted.

Surface treatments can effectively correct a variety of issues including rutting, raveling, skid resistance, and potholes but offer little or no addition to the structural integrity of the pavement system. Recently there has been greater interest in using thin lift hot mix asphalt prepared using Polymer Modified Asphalt (PMA) as an alternative to surface treatments because they are thought to correct the same distress as surface treatments as well as add to the structural integrity of the pavement system. Common types of thin lift hot mix asphalt mixes are fine Stone Matrix Asphalt (SMA-9.5), Open Graded Friction Course (OGFC), and sand mixes. However, to date even less guidance and data is available to industry professionals regarding the relevant material properties and optimum resurfacing time for thin overlay mixes utilizing PMA.

The goal of this research is to develop a guideline for industry professionals regarding the use of thin lift overlay mixes with PMA in New England. This guideline will include thorough research into the existing surface treatments and overlays being used in the New England States as well as development of PMA asphalt mixes that can be used in lieu of the conventional surface treatments. Also explored will be a non-destructive testing method (NDT), the seismic property analyzer (SPA) to determine the optimum time to perform resurfacing, cost/benefit analysis of the various resurfacing options as compared with PMA overlays, and the strengths/weaknesses of particular PMA mixes. Also the NDT device can be utilized to diagnose the problems that lead to the surface distresses.

2.0 Literature Review

2.1 Background

Many of the New England states are adopting "Fix it First" for preventive maintenance on their pavement systems versus the more costly alternative of rehabilitating later in the pavement service life. For the "Fix it First" approach, there are decisions to be made concerning the appropriate preventive maintenance action and the proper timing of application. Currently, in New England, very little guidance is available on these issues. The accepted practice is to resurface the pavement with a surface treatment or thin lift Hot Mix Asphalt (HMA) overlays. Another choice is to replace the roadway entirely, but at a much higher cost.

Surface treatments can be simple pavement seals such as chip seals or fog seals or more complex slurry seals and microsurfacings. The selection of a treatment depends on the existing condition of the pavement. Thin lift HMA overlays are just like any other HMA mix, but usually have a smaller Nominal Mean Aggregate Size (NMAS) and are placed at much smaller thicknesses. Common types include OGFC, SMA, sand mixes, and others. Generally, these mixtures would have a NMAS of 0.187" – 0.375" (4.75 mm – 9.5 mm) and be placed at a thickness less than 1.5" (38 mm). Thin lift HMA overlays are likely to use modified binders. Thin lift overlays incorporating PMA would effectively correct the same distresses (such as rutting, raveling, skid resistance, etc.) as surface treatments. However, as with surface treatments, little guidance is given regarding material properties and optimum resurfacing time for thin lift overlays with PMA.

2.1.1 Overview of PMA

Adding polymers to asphalt has shown to improve roadway performance. The Asphalt Institute states that plastomers stiffen asphalt to increase the high-end service temperature. The increase in high-end temperature improves the performance of the road when it comes to rutting susceptibility (3). The Asphalt Emulsions Manufacturers Association (AEMA) states, "Elastomeric polymers impart durability, flexibility, elasticity, and varying amounts of strength to the asphalt, giving better performance to resist both cracking and permanent deformation" (4). Cracking occurs at lower temperature and can be resisted due to the elasticity and flexibility given to the asphalt by the added elastomer. Permanent deformation, usually in the form of rutting, is resisted because of the durability and strength of the elastomer.

2.1.2 Common Types of Modifiers

Polymers are large molecules made up of many smaller molecules called monomers. Depending on the monomers arrangement and chemical composition the polymer properties can be very variable (1). Polymers can be divided into two categories consisting of elastomers and plastomers. Their categorical names provide an indication of their properties.

Numerous elastomers and plastomers have been added to asphalt to determine their benefits when it comes to pavement performance. Some of the polymers are synthetic while others are natural, but an addition of a modifier to asphalt may lead to better performance when compared to the original asphalt binder. Several modifiers will be further discussed and compared.

2.1.2.1 Elastomers

Elastomers exhibit elastic-like behavior. They deform and stretch a great deal, and have the ability to recover. This ability is due to the polymer's flexible "rubber" backbone (2).

2.1.2.1.1 Styrene-Butadiene-Styrene (SBS)

SBS is a synthetic elastomer that is a widely used modifier. It was the most widely identified modifier in the literature review. This modifier is referred to as a block copolymer since it is arranged of a block of styrene monomers, then a block of butadiene monomers, and a block of styrene monomers again. When introduced and mixed in asphalt, the combination forms a network structure that increases the dynamic modulus component values (G', G"). The University of Louisiana researched SBS and came up with the conclusions that when added to AC-5 and AC-10, improvements were shown in the average strength, tensile and compressive strength, higher viscosity, and improved adhesion. They also determined an optimum polymer content of 5% for SBS in asphalt. Finally it was shown that an AC-5 binder with SBS had viscosity 1.5 times higher than the same binder without SBS (5).

Other studies and research show similar results. The University of Alaska demonstrated that SBS modification improved a pavements rut resistance. Also, the modification improved low temperature cracking resistance of base asphalts. It was concluded that an asphalt base and a polymer modifier should be combined in order to obtain the "lowest possible construction temperatures and improved pavement performance." This was important to aid in construction problems (i.e. emissions and air quality) and decrease life-cycle costs (6).

The University of Florida completed research for the Florida Department of Transportation (DOT) where it was found that SBS had many benefits as well. These included: increased strength at high temperatures, improved adhesion properties, fatigue resistance, rut resistance, bleeding resistance, and low temperature flexibility. These occurred because SBS modified binder exhibited excellent elasticity, plasticity, and elongation properties (1).

The Royal Institute of Technology in Stockholm, Sweden also demonstrated that asphalt modified with SBS had increased stiffness at higher temperatures when compared to unmodified asphalt, which is believed to be because of the polymers elasticity (7).

2.1.2.1.2 Styrene Butadiene Rubber (SBR)

SBR is another synthetic elastomer, which is also a widely used polymer modifier. It is also composed of styrene and butadiene monomers, but they are not arranged in straight blocks of styrene then butadiene like SBS. Rather they are arranged in a random sequence of blocks or even singularly. The styrene monomers are responsible for making the polymer-modified asphalt stronger and more rigid, while the butadiene is responsible for making it more elastic (8). This configuration still greatly benefits the asphalt in relatively similar way SBS does, when the two substances are mixed. In fact, The University of Alaska also tested SBR in the same way as the SBS and found that SBR also improved rut resistance. However, the improvement over the base asphalt was not as large as the improvement between the base asphalt and the one modified with SBS. Also, SBR was seen to create more smoke and had a distinct odor, whereas SBS created less smoke (6).

SBR has been shown to have many of the following advantages (8, 9):

- High solids
- Rapid strength build up
- Improved ageing
- Excellent adhesion

- Increased flexibility
- Increased ductility
- Improved crack resistance
- Increased low temperature flow/decrease high temperature flow
- Improved viscoelasticity
- Stripping resistance

2.1.2.1.3 Styrelf

Styrelf is an elastomeric polymer modified asphalt blend consisting of a homogeneous chemical mixed blend of SBS. This product comes pre-blended as opposed to an outside modifier having to be added and then mixed to an asphalt binder. The North Central Superpave Center learned that Styrelf improved low temperature susceptibility, tensile strength after elongation, elasticity, and age hardening (46). These improvements in turn lead to reduced rutting, stripping, raveling, cracking, and flushing. Valley Slurry Seal Co. listed the benefits of Styrelf as good elastic recovery from point loading, added strength for busy roads (more load), reduced tendency towards brittleness at low temperatures, reduced tendency towards softening at high temperature (that could cause rutting), increased overall stiffness and improved load spreading capacity (17).

2.1.2.2 Plastomers

Plastomers exhibit a more plastic property behavior, therefore they are more hard and stiff at low temperatures and more viscous and easily deformed at higher temperatures (2).

2.1.2.2.1 Ethylene Vinyl Acetate (EVA)

EVA is a plastomeric polymer and a copolymer. Copolymers are formed through a chemical reaction where two monomers are combined and contain repeating structural units. In this case the structural units are ethylene and vinyl acetate. EVA is a synthetic polymer that has proven in service to provide a pavement with beneficial rut resistance and improvements in fatigue life (13). It can be characterized between a semi-rigid, translucent material and transparent rubber material similar to somewhere between low-density polyethylene and polyvinyl chloride (PVC) (14).

BP Bitumen, an asphalt supplier, has seen EVA to be one of the common polymer modification choices in Australia. BP Bitumen says that EVA has seen issues with it stripping properties, which it relates to its brittleness. EVA is used more frequently as a sealer, because it provides high shear resistance to aggregate loss. It has begun to see more use in open-graded asphalt and dense-graded asphalt for its rut resisting properties.

2.1.2.2.2 Elvaloy® (Ethylene Terpolymer)

Elvaloy is a polymer produced and manufactured by DuPont for uses including automotive, electrical, footwear, construction, and others. The polymer modifier was engineered to chemically bond with asphalt and as a result many beneficial properties emerged. The modifier is said to help prevent cracks, potholes, and ruts. DuPont states it recognizes the dynamic stress-strain relationship of the asphalt binder. Their polymer modification helps to keep the PMA flexible over a wide range of temperatures and traffic loads. The type of binder specifically manufactured as the modifier for asphalt is referred to as Elvaloy AM (15).

The University of Louisiana determined the viscosity of an AC-5 with Elvaloy was 3.5 times greater than the same binder without modification (5). This is mostly likely do to the chemical reaction that occurs when the modifier and asphalt are mixed. The National Cooperative Highway Research Program (NCHRP) Project 90-07 "Understanding the Performance of Modified Asphalt Binders in Mixes" tested several modified asphalt binders to understand their performance. Asphalt pavement modified with Elvaloy showed the best resistance to rutting with the Hamburg Wheel Tracking Device (HWTD). This report also showed that modified binders with Elvaloy were not susceptible to moisture damage (16).

2.1.2.3 Other Modifiers and Modified Binders

Other modifiers include those that do not fit into either elastomeric or plastomeric, such as crumb rubber. Crumb rubber is referred to as a particle modifier. Modified binders are binders which all ready have polymers or additives added by the manufacturer.

2.1.2.3.1 Crumb Rubber

Crumb rubber usage is a growing trend due to the environmental effects of so many waste tires. The Intermodal Surface Transportation Efficiency Act of 1991 Section 1038 states that, 5% of the total tonnage of asphalt concrete pavements being built with federal funding should be crumb rubber modified asphalt beginning in 1994 (10). It is produced from discarded tires that are mechanically sheared or grinded to obtain smaller pieces. These smaller pieces, divided by mesh size, can be blended into an asphalt binder to modify it. The process of shredding tires requires a large energy input resulting in a somewhat expensive material. Estimated costs ranged from $0.10 to $0.25/lb in 1996 depending on the mesh size. Therefore, it has not been shown through life-cycle cost analysis to have any advantages of standard HMA mixes (10).

A study by the University of Florida stated, "When GTR (ground tire rubber) is mixed with asphalt binder (135 to 200°C) the rubber particles swell to at least twice their original volume – due to chemical and physical interactions between rubber and asphalt particles – causing a significant increase in the viscosity of the asphalt-rubber mixture" (1). This results in the modified binder having lower temperature susceptibility, a high resistance to plastic deformation at high temperatures, and improved resistance to age hardening.

Numerous other studies and research has been completed testing on the different variables of asphalt modified with crumb rubber. Many of these studies indicate that mixtures incorporating crumb rubber perform better than standard HMA mixes of the same type. A separate report from the University of Florida outlined mixture properties as crumb rubber content increased. The data showed a viscosity increase, higher resistance to loading, improved creep resistance, and fracture time with increasing crumb rubber content (11). PaveTex Engineering and Testing, Inc. confirmed crumb rubber's performance enhancing properties by showing mixtures with crumb rubber have good resistance to reflective cracking and raveling (12).

The Ohio DOT has specific details for the uses of crumb rubber material. One of the uses is incorporation of Chemically Modified Crumb Rubber (CMCR) into a Rubber Modified Asphalt (RMA). Ohio DOT states that adding crumb rubber to hot asphalt improves its performance. Moreover they state that crumb rubber improves pavement performance by decreasing rutting, decreasing reflective and thermal cracking, improving de-icing properties, and reducing traffic noise. Lastly, they state that it will lower maintenance costs due to its increased service life, thus resulting in a lower life-cycle cost (59). This is contradictory to research by Nichols consulting Engineering in Reno, Nevada, which said it has not been shown through LCCA that crumb rubber has any advantages over standard HMA mixes (10).

2.1.2.3.2 Novophalt®

Novophalt was first developed in Europe and later introduced to the United States in 1986. It is produced by adding low density polyethylene and various other polymers (4-6% polymer content) into an asphalt binder in a high shear mixer. Each PMA was formulated to meet the specific requirements for the project to achieve optimum material characteristics. Since so many polymers were blended together, recycled polymers could be used in order to reduce material costs and to protect the environment by saving raw materials.

The North Central Superpave Center found literature referring to the fact that Novophalt stops rutting and shoving at high temperatures. Also, Novophalt increases the pavements resilience and durability, while the binder has improved cohesion/adhesion properties (46). The Novophalt website states that pavements will have reduced rutting at higher temperatures and reduced cracking at lower temperatures. The pavement will be longer lasting and more durable resulting in a longer service life and lower maintenance costs.

2.1.2.3.3 Neoprene

Neoprene is a synthetic rubber that is added to asphalt binders usually in the latex form. This is used frequently in microsurfacing for the following reasons (18):

- High solids
- Rapid strength build up
- Improved aging
- Excellent adhesion
- Increased flexibility and durability
- Improved crack resistance.

Another use for neoprene is as an emulsion in the application of a chip seal. The neoprene gives the emulsion better chip retention properties, improved temperature susceptibility, high temperature viscosity, and elasticity (46). Neoprene alone resists degradation from weather, performs well in contact with oil, makes use of a wider range of temperatures, and adds physical toughness (19).

2.1.3 Preventative Maintenance Issues

There are various strategies agencies can use to ensure their roads are maintained and provide quality surfaces to users. No matter which strategy is chosen, different surface treatments are available for application to roadways for different distress levels, costs, and life-cycles. These surface treatments range surface seals to microsurfacing to thin lift HMA overlays. Chip seals, fog seals, and other related treatments will be discussed later in order to differentiate them from thin lift HMA mixes. Also, a few different thin lift mixes will be described such as OGFC, SMA, and sand mixes. These thin lift mixes often have a polymer modifier added to them for benefits.

One strategy that was relied on by many state agencies was the "worst-first" approach where the roads in the worst condition were fixed first. However, DOTs need to maximize pavement life at a reduced budget due to the ever increasing price of crude oil. For this reason the agencies are switching over to the Preventative Maintenance (PM) approach where the goal is to maximize service life. Through this approach roads must be kept in good condition, meaning roads in deteriorated condition are made a lower priority.

2.2 Types of Thin Lift HMA Mixes

The National Asphalt Pavement Association's (NAPA) Report IS110 "Benefits of Thin Surfacings" indentifies a thin HMA surface as a HMA layer ranging between 12.5 mm (1/2 in.) to 37.5 mm (1-1/2 in.) in thickness. These thin lift mixes are used for preventive maintenance to extend pavement life, improve ride quality, correct surface defects, increase skid resistance, improve surface drainage, enhance appearance, and reduce noise (20). Three mix types will be further discussed.

2.2.1 Stone Matrix Asphalt (SMA)

SMA was developed in Europe and has been used there for over 30 years. It was first developed in order to resist the wear from studded tires, but was found to have great rut resistance. It was not used in the United States until 1991 where "recipe" design procedures were used based on the designs of European SMA's. Most of these mixes in the United States had a NMAS of 19.0 mm or 12.5 mm. However, several other projects in Wisconsin used a NMAS of 9.5 mm, which is better suited for thin lifts. These mixes also showed to be just as rut resistant as the mixes with larger NMAS (21).

The National Center for Asphalt Technology (NCAT) conducted research and testing to determine if SMA mixes would work well as a thin lift overlay. They hoped that NMAS of 9.5 mm and 4.75 mm could be used as a rut resistant thin lift. NCAT noticed that larger NMAS had been difficult to work with and hoped that a finer mix with higher asphalt content would remedy those issues. Gradations were designed and specimens prepared. The mixtures were tested for rutting with the Asphalt Pavement Analyzer (APA) to compare to the Georgia specification of 5.0 mm of rutting at 50°C. This criterion is what the Georgia DOT used for high traffic areas. All mixes passed this specification and the test was run again at 64°C. The worst rutting was 5.4 mm, which was narrowly outside the criteria of 5.0 mm of rutting. Therefore, it was shown that even the smaller NMAS would be rut resistant (21).

NCAT Report No. 97-1 “Performance of Stone Matrix Asphalt (SMA) in the United States,” had completed a nation wide survey of agencies that have used SMA mixes as well as inspect many projects nationwide themselves. This was completed mainly to see the performance of the SMA mixes through different environmental and loading conditions nationwide. A large majority of the projects surveyed had little rutting and some even had no measurable rutting. Thermal and reflective cracking had not been a major issue throughout the survey. It is believed this is because of the higher asphalt content causing a high film thickness. Raveling was not an issue with any of the projects, but fat spots were noted. Fat spots are caused by segregation, draindown, high asphalt content, or incorrect type or amount of stabilizer (22).

NCHRP Report 425 developed a mixture design method, construction guidelines, and Quality Control/Quality Assurance (QA/QC) procedures. Phase I provided information reviewed through literature, as well as testing and results the NCHRP project carried out. Many material properties including aggregate, mineral filler, asphalt binder, and stabilizing additive properties were tested in order to derive the best quality mix design. Various tests were done in order to relate these properties into a well-prepared design procedure. In this report standard practice, specifications, and test methods are available to design satisfactory SMA mixtures with specific properties relating to a project (23). Similar to NCHRP Report 425, NCAT had its own study where it outlined mix design and construction considerations (24).

2.2.2 Open Graded Friction Course (OGFC)

Experimentation of plant mix seal coats, also known as chip seals, caused the creation of OGFC mixes in the United States. It was designed to have the same benefits of a chip seal such as road surface sealing and better skid resistance. However, there were added benefits when chip seal problems such as bleeding, raveling, loose stone, and short performance life were eliminated. When comparing OGFC to dense mixes other benefits are noticed like reduced splash/spray, enhanced pavement marking visibility, reduced surface glare (wet road at night), and reduced tire noise (25).

Europe and South Africa have adapted OGFC for their use. Europe changed the gradations to use coarser aggregate making the mix more permeable. The air voids in the European mixes range from 17-22%. These coarser gradations do not use as much asphalt as other US gradations. For comparison, US OGFC mixes use 5-6.5% asphalt content while the European mixes use 4.5-5% (26).

Both US and European agencies find common ground on the use of modified binders in OGFC mixes. The modified binders provide several benefits to the mix. The first benefit is that modified binders and sometimes including fibers help prevent draindown. Draindown occurs when heat makes the binder liquid resulting in flowing or draining away from the aggregate. Next, modified binders help prevent aggregate loss from wear. Lastly, modified binders improve the pavement system’s rutting resistance (26).

2.2.3 Sand Mixes
NCHRP Synthesis 284 refers to a sand mix as a fine-graded surface mixture with NMAS of no larger than 12.5 mm and high percentages of sand. These types of mixes are designed for a finely textured, smooth, tight surface for reduced permeability. NCHRP mentions two distinct advantages as being low initial cost and easy to construct. The mix is inexpensive because of the high content of sand, which is less expensive compared to other materials. The mix's constructability also comes from the high sand content making it easy to place and compact. Sand mixes leave a smooth finish after compaction and handwork by construction crews is easy with blending and fixing surface blemishes (26).

There are also several disadvantages with the use of sand mixes. Sand mixes tend not to be rut resistant due to the fact the high sand content leaves them with a weak aggregate skeleton. The finely textured and smooth surface can be a hazard when it comes to hydroplaning. Water has no way to leave the surface because it is impermeable and the surface macrotexture leaves no where for it to flow. Another disadvantage, due to the finely textured and smooth surface, is tire noise. Smooth surfaces and low macrotexture produces a more pronounced tire noise (26).

NAPA has also done some research into sand mixes. It was found that sand mixes range in thickness when place from ¼ in. to 3 in., but as the thickness increases the weaker the mix becomes. Thin layers are the most desirable and are used mainly as sealer and raveling prevention. When constructing sand asphalt surfacing it is recommended to use stiffer asphalt binder, add manufactured fines (crushed), use well graded cubical natural sand, and add mineral filler (20).

The Center for Transportation Research and Education at Iowa State University researched an actual placement of a sand surface. It was a high quality mix that included polymer modification to increase temperature stability and reduce low temperature cracking. Observations made not to long after the placement showed the mix had a dense surface, high friction, good workability during construction, quick construction, and minimal changes in surface grade. However, these mixes have limited resistance to reflective cracking (27).

2.3 Types of Surface Treatments
There are many different types of surface treatments and each have their own proper design and usage. For the purpose of this report, surface treatments are an emulsion based mix or any treatment that uses an asphalt/emulsion sprayer followed by an aggregate layer. Several surface treatments will be described in the following sections.

2.3.1 Fog Seal
The Asphalt Emulsion Manual published by the Asphalt Institute describes a fog seal as "a light application of dilutes slow-setting emulsion sprayed on an existing asphalt surface" (28). As stated it is a diluted solution of up to a 5 to 1 water to emulsion dilution, but usually a 1 to 1 ratio is preferred. Fog seals are used in order to renew older,

dry, brittle asphalt surfaces. It seals small cracks, fills voids, and coats surface aggregate to seal it from further weathering. The AI manual also states that if done at the right time it could add to pavement life and delay need for major maintenance or rehabilitation (28).

A report for the South Dakota DOT regarding surface treatments gives more information about fog seals. They state fog seals are used to prevent raveling and renew old, oxidized pavement surfaces. However, fog seals should be used on secondary roads due to the long time it takes for slow setting emulsion to break and the reduction of friction (29).

2.3.2 Chip Seal

The AI describes a chip seal as a single surface treatment. Chip seals are treatments that are prepared by spraying emulsion or binder followed by a layer of small crushed stone (one stone thick) (30). AI outlines that chip seals are used for several reasons including short-term treatment before applying an asphalt mix, to correct raveling, oxidation, permeability, and skid resistance. These are usually applied to light to medium traffic roads, but sometimes used on heavy traffic roads with a polymer modifier and quality stone (28). Conversely, it is not recommended on high traffic roads because of flying chips, a shorter life expectancy, excessive initial noise, and roughness (30).

South Dakota DOT maintains some of the same concepts as the AI manual. Projects in South Dakota showed that rubber added to the chip seal helped it to perform better in relation to its elasticity and adhesion properties. More agencies are leaning towards using chip seals with rubber additives to strengthen the seals for use on roads with heavier traffic loading. Furthermore, their research proved that polymers reduced temperature susceptibility and allowed the road to open to traffic sooner (29).

There are several design methods for chip seal design, which generally includes information on aggregate application rate and the binder application rate. The McLeod Method was the most performed method noted in the review (29, 31). Again, the report from South Dakota DOT outlines this method including the several equations needed. NCHRP Synthesis 342 “Chip Seal Best Practices” outlines a few other methods including Kearby/Modified Kearby, Empirical/past experience, and agencies own formal methods or no method. After surveying US agencies it was found that the McLeod Method was used by 37% being the most widely used (31).

2.3.3 Sand Seal

The AEMA Basic Asphalt Emulsion Manual defines a sand seal as “a spray application of asphalt emulsion followed with a light covering of fine aggregate, such as clean sand or screening” (28). Some locations lack good sources of aggregate for chip seals leading to sand seals as the next best option to correct pavement distresses. Primary uses of sand seals are listed in the manual as follows (28):

- To “…enrich a dry, weathered, or oxidized surface. The sand seal will help prevent loss of material from the old surface by traffic abrasion.”
- To “…prevent the intrusion of moisture and air.” A sand seal creates a barrier preventing air and moisture to underlying layers of the pavement structure. Air

- To "…develop a skid-resistant surface texture." As with chip seals, sand seals also need cubical or angular aggregate to provide a surface with proper frictional properties.

In another source published by the AEMA it provides further benefits on the use of sand seals. The first of which is it will greatly reduce the cost of a preventive maintenance program while covering a large area. Also, AEMA states that since smaller aggregate is used, the aggregate actually gets into the cracks and further strengthens the pavement structure. Lastly, as with any preventive maintenance project, if applied properly and at the right time it will extend pavement life and delay more costly maintenance, rehabilitation, or reconstruction (4).

2.3.4 Slurry Seal

Slurry Seal is one of the most widely used surface treatments worldwide. A diagram of a typical slurry seal mixer can be seen in Figure 1. It is a mixture containing dense-graded aggregate, emulsified asphalt, fillers, additives, and water. The AEMA states it can be used as both a preventive and corrective maintenance technique, but adds no structural capacity to the pavement. The usual thickness for a slurry seal ranges from 3 to 9 mm (1/8" – 3/8"). There are three widely used gradations for a slurry seal mix that are recommended by the International Slurry Surfacing Association (ISSA). Type I is used for crack filling and fine sealing. Type II is used for general sealing and medium texture surfaces. Type III is used for highly textured surfaces (28).

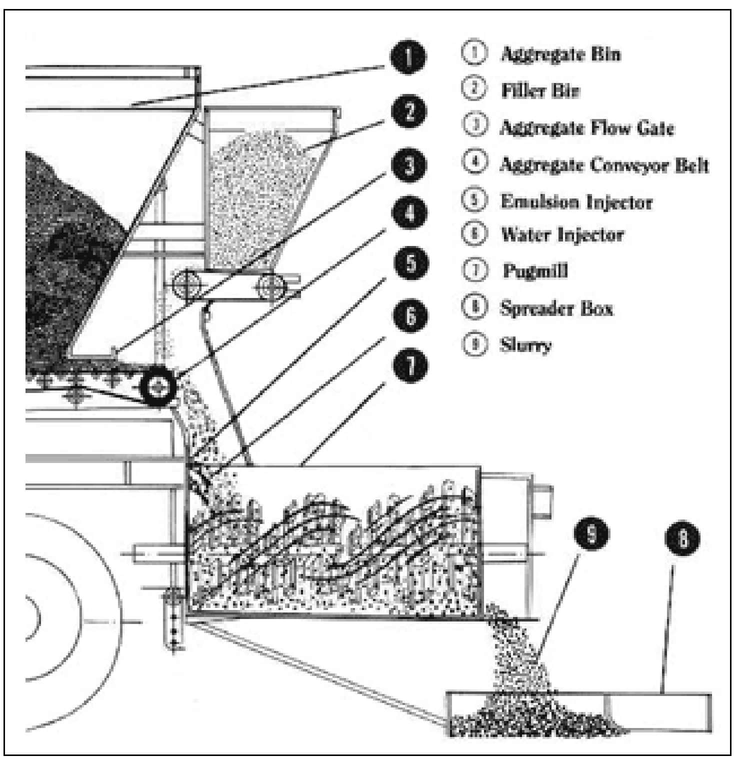

Figure 1. Typical Slurry Seal Mixer (28)

Caltrans has a Technical Advisory Group specifically for microsurfacing projects that have also researched slurry seals. Their report gives job selection criteria for the use of a slurry seal, which are: sound and well-drained bases, surface and shoulders. Another criterion is that the pavement must be free of distresses such as potholes and cracking. If these distresses are present, potholes should be fixed several weeks before surfacing while cracks filled several months before. The report goes on to list other distresses that cannot be addressed including reflective cracking, base failures, and layers that display plastic shear deformation. Distresses that can be addressed by slurry seals are raveling, oxidized surfaces, rutted pavements, and rough pavements (32).

South Dakota DOT provides further information about the performance of slurry seals. Adding to the benefits all ready listed slurry seals perform better in warmer climates, perform better when applied to pavements in good condition, and marginal effectiveness with reflective cracking (returns in 1 year). Slurry seal gradations should be altered when dealing with surfacing pavements with higher traffic volumes. Also, agencies have begun using polymer modification when applying slurry seals in places where there is heavier volume (29).

2.3.5 Microsurfacing

Microsurfacing is very similar to slurry seal except for a polymer modified emulsion binder, better quality aggregates, and a set control additive. Microsurfacing was first produced in Germany in the late 1960's to early 1970's. They were searching for a way to use slurry seal in smaller widths and multiple stone depths. This was desired in order to fill ruts without covering over the expensive road striping lines. It was not introduced to the US until 1980 until it was seen to be a good solution for rutting problems and other issues (33).

As stated by the AEMA microsurfacing is a mixture of well graded aggregate, asphalt emulsion, fillers, additive, and water. Special design techniques are applied when using microsurfacing. These techniques and polymer modifiers give microsurfacing the ability to have multiple stone depths. The set control additive is a special emulsifier, which give the surface the ability to set quickly. When microsurfacing is first placed it appears dark brown, but as water is ejected from the mix through evaporation it turns to black signalizing its drivable (28).

Microsurfacing requires a specialized paver, which continuously lays the mix onto the roadway. Multiple passes can be made, but after one pass the surface typically ranges from 3/8" to 5/8" thick. Also the paver has another special attachment for wheel ruts called the rut box. During the rut filling process larger aggregate particles are distributed "into the deepest part of the rut in order to give maximum stability in the wheelpath" (33). This box allows the paver to fill ruts up to a depth of 1 ½". It is recommended that rut filling be followed by a finishing course to provide adequate water drainage to prevent vehicle hydroplaning (28).

There are many benefits in the use of microsurfacing, which have been noticed by many agencies. Minnesota DOT conducted a statewide microsurfacing research project where it came to several conclusions. Microsurfacing can re-establish the cross section, fill ruts, improve ride quality, increase friction number, and provide more visible pavement markings. However, there are a few ways in which microsurfacing can be undesirable such as increased tire noise and inability to seal reflective cracks (34). Caltrans showed the main mechanism of failure is wearing, but still has a desirable life expectancy. Also, when the surface becomes older and oxidizes abrasion is more likely to occur (32).

2.3.6 Nova Chip®

All States Asphalt Inc. describes the Nova Chip® process as "…a layer of heavily-modified emulsion is applied to the road surface, and within three seconds, a layer of HMA is screeded onto the emulsion. In this instant, the water driven from the emulsion cools the HMA, setting both materials and providing a bond to the underlying surface" (35). The manufacturer goes on to state that the mix is designed around an aggregate size of ½" with a maximum thickness of the structure of 1 ½".

A demonstration section was made in Iowa and the subsequent report provided more information about Nova Chip®. It is an ultra thin hot mix seal originally developed in France. The process needs a special paver since the timing of the emulsion and HMA are crucial. After the mix is placed it is rolled to orient the chips, not for compaction. Observed from this Iowa demonstration was resistance to reflective cracking, reduced headlight glare, and reduced spray from water. A drawback was that the mix was not easily feathered (difficult handwork) for edges or transitions and its price was high (36).

2.3.7 Scrub Seal

A scrub seal, also known as a broom seal, consists of a PMA broomed into the pavement surface, thereby getting into small cracks. This is then covered with fine aggregate and broomed once more to get the sand into the cracks as well. The surface is then rolled. The roadway must have a good profile before applying the scrub seal, since it does not alter the profile. Scrub seals are used to improve skid resistance, prevent oxidation, and seal small cracks against water infiltration (37).

2.4 Use of Maintenance Mixes and/or Surface Treatments in New England

The DOTs of New England have some experience when it comes to maintenance mixes and surface treatments. For this section, the construction specification manuals for each DOT were reviewed in 2006-2207 to see if there was mention of either of these treatments. Several cases were noted that surface treatments had been used or researched in some New England states, but at the time there were no available specifications.

2.4.1 Maine DOT

Maine has only when section for a surface course of HMA pavement. The untreated aggregate surface course is a surface or leveling course containing untreated aggregate or crushed stone. Two gradations are referenced; one for aggregate for untreated surface course and leveling course, and one for aggregate for crushed stone surface. There are a few other requirements given for placement, compaction, and surface tolerance. It must be placed in one even layer with no pockets of fine or course aggregate, compacted at a maintained moisture content, and have a tolerance of +/- 3/8" of the required depth.

There are also reserved sections within the specification manual for bituminous surface treatment and microsurfacing (38).

During the literature review a Maine DOT technical report was found that researched microsurfacing for use as a pavement preservation treatment. A job mix formula was developed using specifications given by the ISSA. Also, the binder used in the mix had to pass several specifications from ASTM. Two project locations were used and test strips of microsurfacing and a 9.5mm HMA overlay were compared. First to be compared was the pavement smoothness. International Roughness Index (IRI) tests were carried out, which Maine DOT specifies an IRI of 1.10 m/km is considered an average. One project site resulted in the overlay maintaining and correcting its smoothness better than microsurfacing. The other project site showed opposite results. Measurements of rut depths on both projects showed the overlay out performed the microsurfacing. Frictional resistance readings were similar for both sites and were above acceptable values, but the microsurfacing sections had a more uniform surface. It was concluded that microsurfacing did not perform as well as the overlay it was compared to. The sections were compared again a year later (39). Microsurfacing section had “slightly more wear and tear” than the overlay. However, it was concluded that microsurfacing was performing just as well as the overlay (40).

2.4.2 Vermont Agency of Transportation

Vermont is one of the New England DOTs that have specifications for a bituminous surface treatment. VTrans gives requirements for all the materials including aggregate types of peastone, stone grits, and sand. Specific requirements for types of emulsions used and different emulsions for different applications are supplied. Four types of bituminous surface treatments are specified and vary in application. In each type how many applications, materials used for each application, application rates, compaction times, and other general information is specified (41).

Another section of the VTrans specification manual outlines an open graded asphalt friction course. It consists of one course of asphalt concrete mix on a prepared foundation. Material requirements are also provided for this including anit-strip and silicone additives. The specification states particularly when the OGFC is used as resurfacing all irregularities and depressions must be corrected in the existing pavement. Therefore, a scratch course may be needed before placing the OGFC (41).

2.4.3 New Hampshire DOT

New Hampshire DOT has two surface treatments currently being specified; a bituminous surface treatment and a plant produced surface treatment. The bituminous surface treatment consists of one more prime or seal coats to a gravel or stone course. This surface treatment that they call a prime coat is basically a fog seal. The use of blotter material (fine aggregate) is specified if the bituminous material has not been able to penetrate within a given time restraint. In this same section it describes the blotter material being applied before the bitumen has set. The roadway is then dragged, rolled, and maintained. Any additional blotter material would be removed. This treatment they call a seal coat, which is basically a scrub seal (42).

The plant produced mix is placed over an existing pavement and can be of one or more courses. There are three mixes that are specified each having a different NMAS. They are 3/8", 5/8", and 3/4" NMAS. These treatments are densely graded thin mix asphalt overlays (42).

2.4.4 Massachusetts DOT

The Massachusetts DOT does not directly specify any surface treatments. They do specify a bituminous concrete pavement that can be applied at different thickness. This can then be used as densely graded thin mix asphalt overlay over existing pavements. This appears to be MassDOT's main approach to surface treatments and preventive maintenance. Also, specified by MassDOT is a protective seal coat emulsion consisting of coal tar pitch dispersed in water. This is used as a fog seal for surface treatment applications (43).

2.4.5 Rhode Island DOT

Rhode Island DOT has a specification for a seal coat similar to the one in New Hampshire. Bituminous material is applied to a gravel foundation, which is then covered with a fine aggregate cover material. Directly after the cover material is applied it shall be compacted first with a power roller and then with a pneumatic roller. Any thin spots should be covered with cover material before rolling. Once rolling has been completed the whole surface should be swept after enough time has passed as not to dislodge imbedded material (44).

Another specification of importance is a rubberized asphalt chip sealing surface treatment specification. This is the same as a regular chip seal except the binder used in this case is polymer modified. The modification is made by the addition of granulated rubber of a certain gradation being added to the neat asphalt binder of PG 58-28. The polymer modified binder is first applied to the surface followed by the application of pre-coated aggregate. The pre-coated aggregate should be heated and maybe covered with a neat binder of PG 58-28 or PG 64-28. After, rolling will commence with pneumatic tire rollers. Once cooled and aggregate has been embedded the surface shall be swept to remove any lose chips (44).

While performing the literature review a presentation was found that had a Rhode Island Decision Matrix for the use of different surface treatments for preventative maintenance. There are four treatments: microsurfacing, rubberized asphalt chip seal, Nova Chip, and elastomeric thin overlay. The matrix is broken up into several categories including traffic volume, land use, road features, location, restrictions, and more. The matrix can be seen in Table 1 (45).

Factors	MICROSURFACING	RUBBERIZED ASPHALT CHIP SEAL	NOVACHIP	ELASTOMERIC THIN OVERLAY
Age of Road	7 (+) Years	7 (+) Years	7 (+) Years	7 (+) Years
Road Type	C2,C3	C2,C4	C2,C3	C2,C3
Traffic Volume	High Car / Low Truck	High Car / (Medium/High) Truck	High Car / High Truck	High Car / High Truck
Pavement Structure	>5 inches	>5 inches	>5 inches	>5 inches
Land Use	All Types	Non Residential, Rural, Farm, Non City, Industrial	City, Urban Upscale	City, Urban Upscale
Pedestrian / Children	OK to use	Do not use	OK to use	OK to use
Road Features				
Curbing	OK	OK	OK	OK
Sidewalk	OK	OK	OK	OK
Distress Factors				
rutting > 3/4in.	OK with shim course	OK with shim course	OK with shim course	OK with shim course
utility trenches	OK with shim course	OK with shim course	OK with shim course or patching	OK with shim course or patching
crack density	Light	Medium/Heavy	Light/Medium	Light/Medium
base failure alligator cracks	No	yes with shim course	yes with shim course	yes with shim course
pothole / raveling	No	Yes with patching	Yes with patching	Yes with patching
Location	City, Urban, Suburban, non commercial	Suburban, Rural, Commercial, Industrial	City, Urban	City, Urban
Restrictions				
Thetmoplastic striping	No (must be removed)	No (must be removed)	Yes	Yes
Rigid Base	No	Yes	No	No
Intersections	Yes	No	Yes	Yes

Table 1. Rhode Island Decision Matrix (45)

2.4.6 Connecticut DOT

Connecticut DOT specifies a bituminous surface treatment similar to the ones previously described in other states. This treatment consists of bitumen applied to a pavement surface followed by the application of fine aggregate. More than one layer of bitumen an aggregate can be applied if specified. The process consists of "sweeping, spotting, dragging, honing, or manipulation of the surface after the application of the sand, distributing, mixing, and smoothing the combination of bituminous material and sand" (46).

2.5 Tests Used In the Evaluation of Thin Lift Mixes and Surface Treatments

Tests for both thin lift mixes and surface treatments were researched through the literature review turning up only several tests. These tests are then broken into two groups consisting of field tests and laboratory tests.

2.5.1 Laboratory Tests

Under laboratory tests several were noticed for the design and testing of surface treatments such as slurry seal and microsurfacing. These tests were found by looking at the design specification procedures in the 2005 Annual Book of ASTM Standards and the ISSA Design Technical Bulletins. Also, one test for thin mixes or overlays from the Texas Transportation Institute is discussed.

2.5.1.1 Loaded Wheel Tester

The Loaded Wheel Tester (LWT) shown in Figure 2 is used in the design of microsurfacing only and referenced in both the ASTM and ISSA design standards. ASTM D 6372, "Standard Practice for Design, Testing, and Construction of Micro-Surfacing" has a section specifically for the LWT test procedure. It states, "This test procedure measures the amount of compaction and displacement characteristics of multi-layered micro-surfacing mixtures under simulated rolling traffic compaction" (47). The specimen is prepared in a mold and allowed to cure. Measurements are taken for the specimens' width and thickness at center and overall weight. The LWT is a wheel tracking device that applies 1,000 cycles at a weight of 125 lbs. After the specimen's width is again measured the percent increase of original thickness is calculated. ISSA Technical Bulletin 147 states this percentage to be a 5% maximum (48). The device can also be used to determine excess asphalt in mixtures using sand adhesion. A specimen is run through the device for approximately 1000 cycles, cleaned of loose particles, and dried. Next a frame is placed around the specimen in the device into which 300 grams of hot sand is added. After 100 cycles the loose sand is removed and the specimen weighed to determine the increase in weight due to sand adhesion (48).

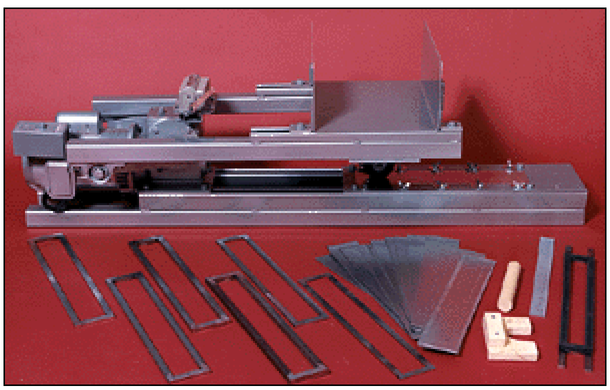

Figure 2. Loaded Wheel Tester
(Picture courtesy www.benedictslurry.com)

2.5.1.2 Abrasion Tester

The Abrasion Tester (Figure 3) used for performing the Wet Track Abrasion Test (WTAT) is used for both slurry seal and Microsurfacing design, with different requirements for each. The machine itself is basically a mixer where a rubber hose is attached. In place of a bowl a round thin mold with mix is positioned.

TB 100 "Test Method for Wet Track Abrasion of Slurry Surfaces" is the ISSA standard for this test. The ISSA and ASTM procedures both reference the TB in their published design guidelines. Both show how the WTAT is performed with specimens. The test procedure consists of soaking a specimen made from a circular flat mold after it has cured. Weigh the specimen before the soaking period begins. Soaking takes place for one hour for slurry seal, while microsurfacing has a one hour and a six day soaking period. Then the mold and specimen is fixed to the mixer where a rubber hose is attached to the mixer and bears on the surface. The mixer is turned on for a certain period of time and the hose abrades the surface. The specimen is washed of debris and dried in an oven. Once completed, the specimen is weighed again and the difference in weight is calculated. The wear value is then expressed in grams per surface area (square foot or square meter) (47, 48).

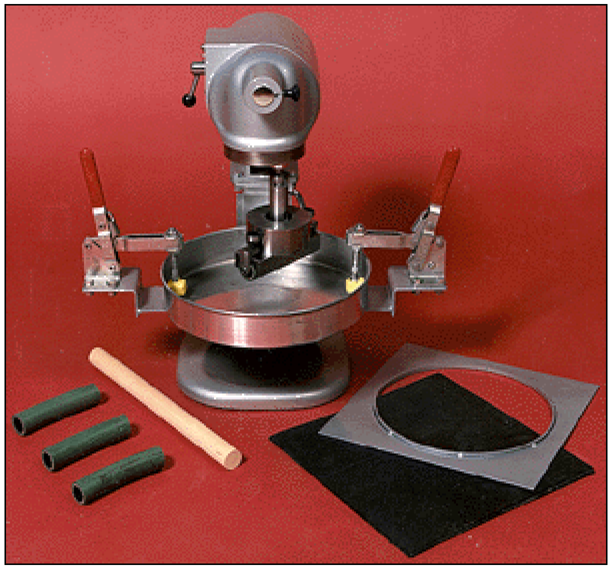

Figure 3. Abrasion Tester
(Picture courtesy www.benedictslurry.com)

<u>2.5.1.3 Flexural Tension Tester</u>

The ISSA TB 146 "Flexural Tension Test Method for Determination of Cracking Resistance of Slurry Mixes at Ambient and 4°C", discusses the use of the Flexural Tension Tester (FTT) shown in Figure 4. The device itself takes specimens from long skinny molds, same as LWT, and flexes a plaque mounted specimen. The scope of the test cover "measurement of the relative ambient and low temperature cracking resistance of compacted, thin-layers emulsified asphalt-fine aggregate mixes such as slurry seal and microsurfacing materials" (48). Samples are compacted using the LWT in the molds described in that section. The specimen is then placed in the FTT where compression is applied shaping the specimen into an upward arch. The operator must take care to observe when the first crack appears and the machine is turned off. A reading of the linear distance the compression bracket traveled is recorded. The test can also be conducted in a refrigerated chamber, thus finding its crack resistance at low temperatures. The same steps are taken during the experiment (48).

Figure 4. Flexural Tension Tester
(Picture courtesy http://www.benedictslurry.com/BSSPresentation.pdf)

2.5.1.4 Cohesion Tester
A cohesion tester is another importance piece of equipment when it comes to designing slurry seals and microsurfacing treatments. The machine has a pneumatically operated rubber foot that is positioned on the treatment surface. Pressure is applied to the foot and the foot spins. The tester is lightweight and portable making it used in the laboratory and the field (47).

The test that the cohesion tester performs is the called the cure time or the cohesion test. The ASTM refers to it as the cohesion test when designing microsurfacing, where it determines the set time. When designing a slurry seal the ASTM refers to it as the cure time since that is what is being determined. Both tests have basically the same method. The rubber foot with an applied pressure is positioned on the surface. Torque is then applied as the foot rotates on the surface. The procedure is repeated in intervals of 15-30 minutes until the torque is maximized or the foot moves freely with no dislodged particles from the surface (47). Graphs are given in both the ASTM 3910 and the TB 139 procedure, "Test Method to Classify Emulsified Asphalt/Aggregate Mixture Systems by modified Cohesion Tester Measurement of Set and Cure Characteristics." The graph shown can be used to determine this system classification given the results from the cohesion tester (48).

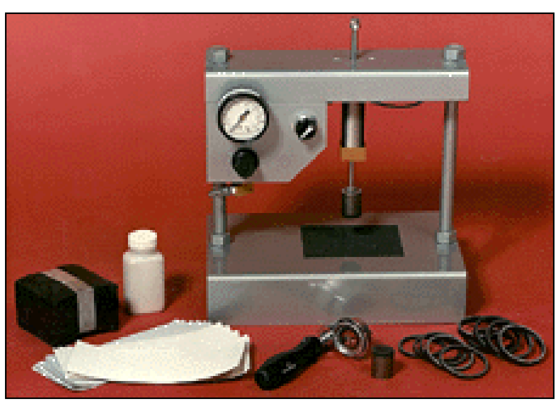

Figure 5. Cohesion Tester
(Picture courtesy www.benedictslurry.com)

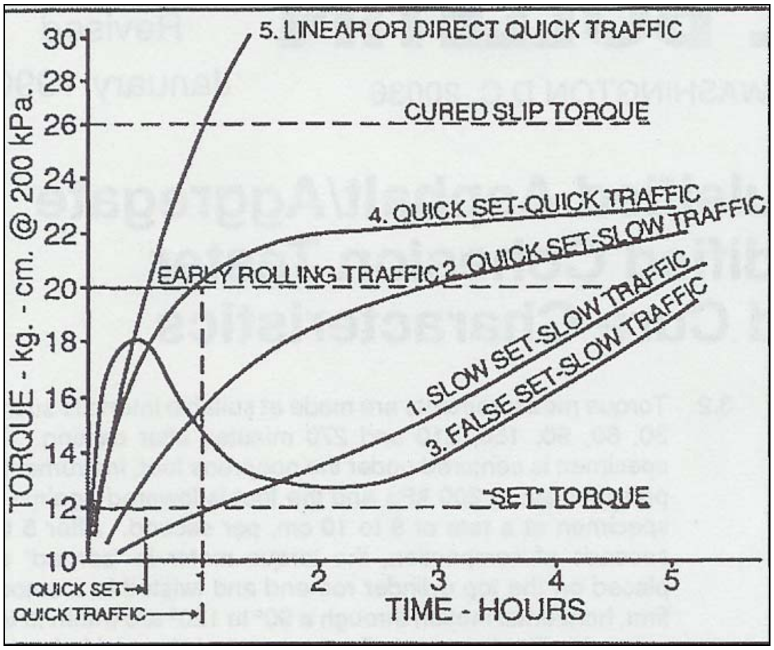

Figure 6. Cohesion Test Classification
(Design Technical Bulletin ISSA)

<u>2.5.1.5 Overlay Tester</u>

The Texas Transpiration Institute has developed an overlay tester to test reflective cracking resistance of field cores and laboratory-produced specimens. Specimens are prepared and cut to size in width and length. The thickness that the machine tests efficiently ranges from 1.5" to 2". Temperature, opening displacement, loading rate, and the load can all be controlled. Specimens are attached to two mounting plates using epoxy. The assembly is put together and a displacement is applied to the specimen. The displacement is applied in cycles over a certain period of time to determine the reflective cracking life of the specimen (49).

Figure 7. Overlay Tester - Test Specimen Assembly

2.5.2 Field Tests
Not many field tests were noted for either surface treatments or thin asphalt overlays. Most of the time visual surveys are made to determine how the treatment or overlay is performing. Different distresses and failures are noted such as raveling, bleeding, and cracking. The percentage of each (or linear feet for cracking and square foot for raveling and bleeding) is calculated and this is monitored over a period of time to see if these distresses worsen (29). If it does happen that these distresses get worse, then the rate at which it is happening must be determined. Also, a similar survey can be done for thin overlays and microsurfacing, but also include rutting. Microsurfacing can be used as rut filler; however, if it fails to work properly it should be noted. Thin overlays, for the most part, should not rut much because of their relatively small thickness. Some rutting might occur in the thin overlay layer, but the underlying layers could be responsible for the rutting.

2.5.2.1 Thin Layer Density Gauge
Newly developed thin lift nuclear density gauges are starting to be used for collecting data for top layers of pavement. The gauge is designed to measure the density of thin asphalt concrete layers ranging from 1” to 4”. This can now be done without any influence from the underlying layers or materials. The previous method consisted of a lesser density gauge paired with a nomograph to determine the density. The gauges are able to meet all requirements of ASTM D 2950 “Standard Test Method for Density of Bituminous Concrete in Place by Nuclear Methods” (50).

2.6 Comparison of Maintenance Mixes and Surface Treatments
Thin lift maintenance mixes and surface treatments are difficult to compare because they are very different in several aspects. Cost, life expectancy, ride quality, performance, etc. are all different. Comparisons can be made, but the different aspects should be weighed differently.

2.6.1 Uses
There is variance between these two main groups on what type of roads to apply the treatments. The general assumption is that thin lift overlays should be used more on roads with heavy traffic, while surface treatments are left to roads with light to moderate traffic.

However, chip seals and sand seals that use high quality aggregates and binders (even modified binders) can have the ability to be used on roads with heavier traffic. Chip seals should be considered as a preventative maintenance on high volume roads as long as quality aggregate and modified binders are used. Of course, the consideration should be to properly test the chip seal design with a heavy traffic load before applying it to a roadway (28).

Other surface treatments like slurry seal and microsurfacing are being developed to be more usable on heavier trafficked roads. There are three gradations given by the ISSA for slurry seal mixes. The Type II is used for moderate traffic pavements. Its benefits include protection from oxidation, water damage, improved friction, raveling correction. The Type III gradation is used for heavy traffic roads. Some of its benefits include heavy application rates and high friction values among others. Microsurfacing has similar types of gradations that behave similarly. For instance, the Type II gradation is for general resurfacing of streets and moderate traffic roads, while Type III is for heavy traffic densities (28).

Thin mix overlays can be adapted to be applied to roadways of different traffic volumes. For low volume roadways the issues to be resolved are raveling and cracking. The mixes for these applications are either dense graded or sand asphalt. A couple of mixes are outlined in NAPA IS 110 for both low volume and high volume roads. High volume roads must have durable mixes with good friction and rut resistance. The mixes used for these applications are SMA and OGFC.

2.6.2 Performance

It is difficult to accurately understand how long the treatments will last or how much longer the pavement life will be extended. In one report published by the American Society of Civil Engineers (ASCE) literature research showed that in New York chip seals reported extending the pavement life by 3-4 years, while in Manitoba, Canada it extended it to 10-12 years (32). Another example would be the South Dakota DOT, which believed the performance life to 4-7 years with a possibility of lasting 10 years. This same performance life was what they also predicted for microsurfacing (29). Other literature suggested that microsurfacing and slurry seal being more regulated with better materials would last longer than a general chip seal. Also, it depends on how the pavements condition is before the treatment is applied.

A general finding throughout the literature was that surface treatments did not last as long as thin mix asphalt overlays. Several instances were found for the performance life or extended pavement life of SMA and OGFC mixes. SMA is believed to extend the pavement life by up to 40% (51). The same South Dakota DOT report gave OGFC mixes a performance life of 10-12 years.

2.6.3 Cost

Generally, thin lift mixes cost more when compared to other surface treatments. However, with higher quality materials microsurfacing and slurry sealing may become more expensive. A Life Cycle Cost Analysis (LCCA) is a very important tool when determining the type of treatment and its time of application. State agencies would like to take care of maintenance when needed, but it is not always the case when funding is unavailable.

In a follow up article to AI Engineering report 215 LCCA was shown for five scenarios of a pavement system with polymer modification. Each scenario added polymer modification to more and more courses (i.e. binder course, wearing course, base course) and one scenario with no modification. The unmodified had the least initial cost and adding more and more polymer to different courses drove the initial course higher.

However, with less maintenance needed on roads with polymer modification the life cycles cost actually got less with polymers in the different courses (52).

Thin lift asphalt mixes can be more costly, as mentioned, due to the fact more materials are used for producing them. NCHRP Synthesis 284 demonstrates the differing costs of various overlays in different states. The lives of these overlays are all different from state to state and so are their prices. To generalize the information it appears that dense mixes are the least expensive, followed by OGFC (neat binder), then OGFC modified and SMA are relatively similar. However, the price does get more expensive, but the life of the overlay also increases. This should stress the fact that LCCA is an important step in the process (26).

Since there are so many different types of surface treatments there is a wide range of costs. The chip seal surface treatment itself has a wide range of prices, because of the many possibilities for materials. Depending on aggregate size, fractured faces, type of binder and polymer modification prices for chip seal were found to range from $0.34/yd^2 to $1.51/yd^2. Fog seal, being only emulsion or binder, is a little less costly at around $0.45/yd^2. Slurry seal and microsurfacing were more expensive at $0.90/yd^2 and $1.25/yd^2 respectively (29). These prices came from the Foundation for Pavement Preservation (FP^2).

2.7 Optimum Time for Preventive Maintenance

To date, there has only been one project that attempted to optimize preventive maintenance treatment application timing. The NCHRP Project 14-14 "Guide for Optimal Timing of Pavement Preventive Maintenance Treatment Applications" has undertaken research to help better understand optimal timing to improve costs (53).

2.7.1 Current Methodologies

NCRHP Project 14-14 developed a methodology for calculating the optimal time to apply preventive maintenance treatments for both rigid and flexible pavements. In the final report, NCHRP Report 523, the methods outlined are based on a benefit/cost ratio approach using condition indicators, performance data, and computer software (OPTime) to calculate optimal timing. The report concluded with an overview of a systematic approach for preventive maintenance. The approach is as follows (53):

1) First, the program must determine its objectives for preventive maintenance. These objectives should include what the program wants to accomplish and what specific measures of performance it should impact.
2) Next, the program must have guidelines for selecting surface treatments. Different treatments can be used in different circumstances, so guidelines should aid in the proper choice of treatment. Guidelines should include information for project selection, construction, quality assurance/quality control, and troubleshooting.
3) A performance level for the "do-nothing" approach as outlined in the report should be defined. The "do-nothing" approach shows how the road would

4) Measures of performance also need to be defined. The benefits of using surface treatments can only be noticed when certain thresholds of performance criteria are defined.
5) Finally, analysis of the data can be performed and used to determine the optimal timing for preventive maintenance treatment application.

2.7.2 Tests for Determining Rehabilitation Needs

Several tests have been used to figure out if roadways are structurally sound or if they are in need of rehabilitation or maintenance. This project looks into the SPA specifically, but the Falling Weight Deflectometer (FWD) is another device that can be used. The basic use for these devices would be to test the road for its structural properties. Once knowing these properties a plan for maintenance, rehabilitation, or to keep it as is can be decided upon. If the road shows structural weakness it is in need of rehabilitation. If the road has a good structure with minor cracking or several years old a preventive maintenance plan is more likely. If the road has a strong structure with no cracking then perhaps nothing needs to be done for a few more years.

2.7.2.1 Seismic Property Analyzer (SPA)

The SPA measures sonic, ultrasonic, and resonant vibrations by making stress wave measurements. This procedure is a non-destructive method for testing structural properties of asphalt pavement. It will automatically take the readings and interpret the results. The machine itself comprises of a seismic source, two receivers (to collect the vibrations), and an electronics package (i.e. laptop). The laptop has the software required to take measurements and interpret the results (54).

In a preventive maintenance program visual surveys of the roadway do not always show problems that could be occurring beneath the surface. The only ways to discover those distresses are using a non-destructive method such as the SPA. To more accurately describe the process time records acquired with vibration sensors are combined and used to determine an experimental dispersion curve. Using this curve and an inversion procedure the elastic modulus of a pavement structure can be estimated (54).

2.7.2.2 Falling Weight Deflectometer (FWD)

The FWD is another non-destructive testing apparatus that tests the physical properties of a roadway structure. This testing device is also used to calculate the elastic modulus of the pavement structure. An actual load pulse is delivered to the pavement surface mimicking the load of a rolling wheel (dynamic load). A load cell measures the exact load which is applied to the surface. There are deflection sensors mounted to the device certain distances (radially) from where the load is applied. These sensors are used to measure the pavement deformation due to the load.

“Backcalculation” can be used in order to determine the modulus of each layer in a pavement system from the FWD data. This is done through an iterative procedure using the deflections measured by the sensors. According to Dynatest®, a manufacturer of

FWDs, “This information can in turn be used in a structural analysis to determine the bearing capacity, estimate expected life, and calculate an overlay requirement, if applicable (over a desired design life)” (55).

2.8 Overall Literature Review Summary

Many aspects of PMA and surface treatments have been compared and contrasted as well as different testing and designing strategies. Thin lift maintenance mixes, especially those with polymer modifiers, seem to perform very well but at a higher cost. This cost may be balanced in a LCCA since these mixes last for a greater period of time when compared to surface treatments. However, surface treatments seem to be coming into their own as more quality materials are being used. These quality materials show greater benefits of performance and life whether used in chips seals, slurry seals, or microsurfacing. Even these surface treatments are getting modified with polymers added to the binder or emulsion (depending on surface treatment). These quality materials do however come with a higher price and therefore could be just as beneficial as a thin mix overlay. The benefits of a LCCA would be the only solution to determine what strategy is more beneficial.

Certain requirements need to be determined as to what is a respectable life cycle cost for these different strategies. Budgeted money should only be made available for the most cost beneficial strategies. Testing should be done to compare different performance and quality aspects for the strategies. Then a side by side comparison should be drawn in order to which treatments have the better performance, better qualities, and better cost. Also, both strategies could be combined and used at different levels. These levels could be based on traffic, cost, performance requirements, etc. That method could be summarized in a decision matrix similar to the one mentioned from RIDOT.

3.0 Survey of State DOT’s

An internet survey was created in an attempt to evaluate the current state of practice with regards to thin lift overlay maintenance mixes and surface treatments. A copy of the survey is available in Appendix A of this report. This thirty one question survey was developed in an attempt to expand on the findings of the literature review and to determine the current methodologies employed by industry professionals to determine the optimum time to rehabilitate a particular pavement and the process for choosing a rehabilitation method.

The survey was sent to the New England Transportation Consortium (NETC) project technical committee for comments and approval prior to it being sent for response solicitation. In 2007, once approved by the technical committee, the survey was distributed via email to 155 industry professionals including members of each New England DOT, Federal Highway Administration (FHWA), government agencies, other state DOT agencies, and local/municipal agencies. The total survey response rate was 9%. A detailed summary of the survey results and responses is available in Appendix B.

3.1 Section 1: Preventive Maintenance Strategies

Based on the survey responses, 86% of respondents stated that their agency utilizes a preventive maintenance program based on either a condition survey, a Pavement Management System (PMS), or an in-house methodology. The method of selection for using either a surface treatment or lift HMA overlay varied amongst respondents with decision trees, functional classification of the roadway, existing pavement condition and treatment cost being the most noted responses. In terms of timing of preventive maintenance application, the majority of respondents (57%) did not have a methodology to select the appropriate time to apply a strategy, however many respondents stated they are in the process of developing a methodology. For remainder of the respondents, the most noted methods for proper timing were based on personal experience and an automatic programmed time after reconstruction or resurfacing.

For the majority, most respondents stated that visual condition survey (100%) and the FWD (86%) were the equipment used to determine pavement distress or failure for their agency. These equipments were followed by inertial profilers (58%), Ground Penetrating Radar (GPR) (14%) and other equipment (21%) like friction testers and lock-wheel skid trailers. In terms of the agency purpose for the equipment, visual condition survey was the most noted response for pavement preservation. The purpose of the FWD was most noted for structural evaluations.

For a method to choose different types of surface treatments or thin lift overlay mixes, the majority of respondents noted that decision trees, existing pavement condition and experience were selection factors.

3.2 Section 2: Thin Lift Overlay Maintenance Mixtures

The majority of respondents defined thin lifts as less than or equal to 1.5 inches (51%) or less than or equal to 1.0 inches (21%), while only 7% define them as less than or equal to 2 inches. These thin lift overlay maintenance mixtures are used or specified by 71% of the respondents. A dense graded mixture (71%) was the most highly specified thin lift overlay mixture with OGFC, SMA, and sand mix equally (29%) the second most noted. Each respondent provided different surface preparation requirements for the different types of mixtures used by the agency based on existing pavement condition (See Appendix B – Question 10). There was no universally noted surface preparation methodology. The respondents stated that cracking (79%), surface friction (72%) and waterproofing (64%) were the main distresses that their agency hopes to resolve with thin lift overlay mixtures. Most of the respondents (77%) noted that they utilized some sort of mix design method for thin lift HMA overlays, with Marshall and Superpave being the most noted responses. Only 15% stated they followed a recipe when developing thin lift HMA overlay mixtures. In terms of cost for thin lift HMA overlay mixtures, prices noted varied from $3-$8 per square yard and/or $55 to $75 per ton.

In terms of benefits of thin lift HMA overlay mixtures, respondents noted that they were more resistant to distress (cracking) than conventional HMA, improved ride quality, had better skid resistance, and reduced noise. In terms of limitations of thin lift HMA overlay mixtures, respondents noted that they exhibited reflective cracking (sometimes within a year of placement), do not fix distress but rather prevent deterioration, limited the construction window, and have a higher cost.

3.3 Section 3: Surface Treatments

The majority of respondents (93%) stated their agency uses surface treatments. Micro surfacing (86%), chip seal (71%), Nova Chip (71%), emulsion chip seal (57%), and fog seal (50%) were the most highly noted. Similarly to thin lift HMA overlay mixtures, each respondent provided different surface preparation requirements for the different types of surface treatments used by the agency based on existing pavement condition (See Appendix B – Question 21). The respondents stated that oxidation (79%), raveling (71%), cracking (71%), surface friction (71%), waterproofing (58%) and rutting (50%) were the main distresses that their agency hopes to resolve surface treatments. In terms of cost for surface treatments, prices noted varied from $1-$5 per square yard based on the specific type of treatment.

In terms of benefits of surface treatments, respondents noted that they extend pavement life, delay need for rehabilitation, and reduce construction costs. In terms of limitations, respondents noted that surface treatments have temperature limitations (microsurfacing and chip seals), require experience personnel to know when and how to apply based on road condition, and may be susceptible to snow plow damage (chip seals).

In terms of equipment and tests for surface treatments, emulsion testing and the ISSA Technical Bulletin tests were the most widely noted responses.

3.4 Section 4: Polymer Modified Asphalt

Respondents stated that SBS (57%), SBR (50%), and crumb rubber (21%) were the most used polymers or modified binders for thin lift HMA overlays. For surface treatments, SBS (29%) and crumb rubber (29%) were the most used polymers or modified binders. In terms of target Performance Grade (PG) binder grade for polymer modified asphalts, the results varied greatly due to responses from respondents from around the United States. Each specific response is available in Appendix B – Question 28.

For specifying the use of polymer modified asphalt, most respondents (71%) stated they relied on the PG of the binder. When deciding on the use of one polymer modified asphalt versus another, respondents indicated that lifetime (50%), other factors such as performance and climate (36%) and cost (29%) were the factors. The advantages of using polymer modified asphalt were noted as reduced cracking, reduced rutting, reduced thermal cracking, and extended pavement life. No disadvantages of using polymer modified asphalt were noted.

4.0 Objectives

The main objective of this study was to develop thin lift overlay mixtures with polymer modified asphalt for use in New England. Specifically, the objectives were to:

- Define and compare thin lift overlay maintenance mixes and surface treatments currently used in the New England States.
- Evaluate the thin lift overlay maintenance mixes and surface treatments currently used in the New England States and compare to those currently used worldwide.
- Determine the current New England DOT procedures for picking rehabilitation methodologies.
- Perform and evaluate non-destructive testing to better determine the optimum time to apply surface treatments or thin lift overlay mixes to the existing pavements in order properly prioritize rehabilitation projects.
- Evaluate the benefits and drawbacks of using PMA thin lift mixes versus surface treatments with lab testing.
- Evaluate the cost comparisons between PMA thin lift mixes and surface treatments.

5.0 Non-Destructive Field Testing

An original component of this research was to conduct field testing using Portable Seismic Property Analyzer (PSPA) to determine and evaluate the threshold parameters regarding the time when maintenance is required. A list of roads to test was to be supplied by the committee members at a project update meeting. No list of roads was able to be obtained for this testing. Therefore additional polymer modified asphalt binders were included for mix design and performance evaluation as outlined in Section 6.0 and 7.0.

6.0 Polymer Modified Asphalt Mixture Design

For this study, six asphalt binders were used in the mixture design development. One binder was a non-modified binder with a performance grade of PG64-28 which is typically specified in the New England region. This binder served as the control. The remaining five binders were modified. In total, six mixture designs were completed for this project.

6.1 Binders

The control and modified binders that were utilized in this study are shown in Table 2. Additionally, this table indicates the type of modification utilized, if any. Because of the proprietary nature of the asphalt binders, the amount and exact composition of the modifier utilized in some binders was unavailable. The mixing and compaction temperatures for each binder were supplied by the binder manufacturer and utilized throughout the study.

6.2 Aggregate

The aggregate utilized for the mixture designs in this study originated from a crushed stone source in Wrentham, Massachusetts (Aggregate Industries). Three different aggregate stockpiles were obtained from the source: 9.5 mm crushed stone, stone dust, and washed sand. The aggregate properties of each stockpile are shown in Table 3.

Table 2. Binders Utilized for Study

Binder	Modification	Mixing Temperature	Compaction Temperature
PG64-28 Control	None	165-161ºC	157-153ºC
PG64-28 + PPA	Poly Phosphoric Acid (PPA)	163-159ºC	154-149ºC
PG64-34 SBS	Styrene-Butadiene-Styrene (SBS)	154-150ºC	143-139ºC
PG76-22 SBS	Styrene-Butadiene-Styrene (SBS)	163-157ºC	157-152ºC
PG64-22 + GTR	12% Ground Tire Rubber (GTR)	171-158ºC	146-135ºC
PG64-28 + Latex	2.0% Latex (BASF Butanol NX1129)	172ºC	169ºC

Table 3. Average Aggregate Stockpile Properties

Sieve Size	9.5 mm Crushed Stone	Stone Dust	Washed Sand
19.0 mm	100	100	100
12.5 mm	99.9	100	100
9.5 mm	96.7	100	100
4.75 mm	37.5	99.4	98.6
2.36 mm	3.3	81.6	81.7
1.18 mm	1.7	56.1	56.5
0.600 mm	1.6	38.4	38.1
0.300 mm	1.6	25.3	23.5
0.150 mm	1.5	16.1	12.7
0.075 mm	1.4	11.2	6.6
Specific Gravity, Gsb AASHTO T84/T85 (56)	2.611	2.600	2.631
Absorption, %	0.54%	0.77%	0.51%
Coarse Aggregate Angularity, % ASTM D4791 (57)	97.0%	n/a	n/a
Flat and Elongated Particles, % ASTM D5821 (57)	3.0%	n/a	n/a
Fine Aggregate Angularity, % AASHTO T304 (56)	n/a	47.2	47.9
Sand Equivalent, % AASHTO T176 (56)	n/a	73.0	90.0

6.3 Mixture Design

A 9.5 mm Superpave mixture was developed in accordance with American Association of State Highway and Transportation Officials (AASHTO) M323 "Superpave Volumetric Mix Design" and AASHTO R35 "Superpave Volumetric Design for Hot Mix Asphalt" (56) using each of the six asphalt binders. The mixture design was a coarse-graded Superpave 9.5 mm. The design mixture gradation and combined aggregate properties for the design are shown in Table 4.

Table 4. Mixture Gradation and Combined Aggregate Properties

Sieve Size	9.5 mm Mixture Gradation	9.5 mm Superpave Specification Range
12.5 mm	100	100 min.
9.5 mm	98.4	90-100
4.75 mm	68.4	90 max.
2.36 mm	42.6	32-67
1.18 mm	29.1	-
0.600 mm	20.0	-
0.300 mm	13.0	-
0.150 mm	8.0	-
0.075 mm	5.2	2-10
Coarse Aggregate Angularity, % ASTM D4791 (57)	97.0%	95/90
Flat and Elongated Particles, % ASTM D5821 (57)	3.0%	10 max.
Fine Aggregate Angularity, % AASHTO T304 (56)	47.6%	45% min.
Sand Equivalent, % AASHTO T176 (56)	81.5%	45% min.
Combined Specific Gravity , G_{sb}	2.613	-

The design Equivalent Single Axle Loads (ESALs) for this project was selected as 3 to <30 million. This ESALs level was consistent with high traffic surface course mixtures in New England, US. The design Superpave gyratory compactive effort for this ESALs level was N_{design} = 100 gyrations.

Specimens were batched, mixed and short-term aged at the compaction temperature for two hours in accordance with AASHTO R30 "Mixture Conditioning of Hot Mix Asphalt (HMA)" (56). After aging, specimens (150 mm diameter) were compacted in the Superpave Gyratory Compactor (SGC) to N_{design}. The volumetric properties of the SGC mix design specimens for each binder are shown in Table 5. Mixture were designed to meet the Superpave volumetric requirements for air voids, Voids in Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA), and Dust to Binder Ratio. In some instances it was not possible to meet the VFA requirements since AASHTO M323 specifies an increase in the acceptable VFA range from 65-75% to 73-76% for 9.5 mm mixtures with design traffic levels greater than 3 million ESALs. In these cases the mixtures were designed as close to the VFA range as possible without negatively impacting the other volumetric properties.

Table 5. 9.5 mm Superpave Mixture Properties at N_{design}

Properties	PG64-28 Control	PG64-28 + PPA	PG64-34 SBS	Superpave Specification
Binder Content, %	5.80	5.80	5.80	-
Air Voids,%	3.9	4.3	4.1	4.0%
VMA, %	15.5	15.9	16.2	15% min.
VFA, %	74.6	73.3	74.6	73 – 76
Dust to Binder Ratio	0.8	0.8	0.8	0.6 -1.2

Properties	PG76-22 SBS	PG64-22 + GTR	PG64-28 + Latex	Superpave Specification
Binder Content, %	5.80	7.30	6.25	-
Air Voids,%	3.5	4.0	4.5	4.0%
VMA, %	15.1	18.5	16.9	15% min.
VFA, %	77.1	78.3	73.4	73 – 76
Dust to Binder Ratio	0.8	0.6	0.8	0.6 -1.2

VMA = Voids in Mineral Aggregate
VFA = Voids Filled with Asphalt

7.0 Polymer Modified Asphalt (PMA) Mixture Performance Testing

An original component of this research was to conduct performance evaluations in the laboratory using the Model Mobile Load Simulator (MMLS) and PSPA. However, after several attempts to compact the asphalt mixtures in the MMLS device, it was obvious that achieving target density with these types of mixtures was not attainable. Moreover since the mixtures developed under this study were to be used as an overlay treatment in lieu of a surface treatment, the main area of performance concern in the New England region would be environmental related (low temperature) cracking. Thus it was decided to eliminate the MMLS and corresponding PSPA testing and continue to evaluate additional polymer modified asphalt binders. Thus, both dynamic modulus and Indirect Tensile Test (IDT) performance testing were conducted on all the mixtures developed in Section 6.0.

7.1 Dynamic Modulus Testing

Complex dynamic modulus |E*| testing was conducted to determine the impact of the binder type and modification on the overall mixture stiffness. Increased mixture stiffness may lead to mixtures that are more susceptible to environmental related (low temperature) cracking.

In order to determine the dynamic modulus, test specimens were subjected to a sinusoidal (haversine) axial compressive stress at the different temperatures and frequencies in the Asphalt Mixture Performance Test (AMPT) device. The resultant recoverable axial strain (peak-to-peak) was measured. From this data, the dynamic modulus was calculated. The dynamic modulus data was then utilized to develop mixture master curves. The master curve shows the stiffness of the mixture in terms of dynamic modulus over varying temperatures and frequencies.

7.1.1 Specimen Fabrication and Testing

The dynamic modulus test specimens were fabricated using the SGC. Each mixture was batched, mixed and short-term aged for four hours in accordance with AASHTO R30 "Mixture Conditioning of Hot Mix Asphalt (HMA)" (56). After aging, specimens (150 mm diameter x 170 mm tall) were compacted in the SGC. These specimens were subsequently cored and then cut to the final specimen dimensions of 100 mm in diameter by 150 mm tall as suggested in AASHTO TP62 "Determining Dynamic Modulus of Hot Mix Asphalt (HMA)" (58) and NCHRP Report 614 "Proposed Standard Practice for Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor" (59). Each cut specimen was tested to determine the air voids. The target air void range was 7±1% which correlated to the expected in place density after construction. Three replicate of the dynamic modulus specimens were fabricated for each binder included in this study.

Dynamic modulus testing was completed in AMPT in accordance with AASHTO TP62 (58) and the draft specification provided in NCHRP Report 614 "Proposed Standard Practice for Developing Dynamic Modulus Master Curves for Hot-Mix Asphalt Concrete Using the Simple Performance Test System" (59). Specimens for all binders except the PG76-22 were tested at temperatures of 4, 20, and 40°C and loading frequencies of 10, 1, 0.1, and 0.01 Hz (40°C only) as suggested in the specification provided in NCHRP Report 614 (59). The specimens fabricated with the PG76-22 binder were tested at temperatures of 4, 20, and 45°C and loading frequencies of 10, 1, 0.1, and 0.01 Hz (45°C only) as suggested in the specification provided in NCHRP Report 614 (59).

7.1.2 Results

The dynamic modulus data is shown in Figure 8. The error bars on the dynamic modulus results shown in Figure 8 are the 95% confidence intervals. Error bars that overlap indicate that the modulus values are not significantly different. The results indicated, for the majority, the modified binders utilized yielded mixtures with stiffness similar to the control mixture, with the exception of the PG64-34 which was consistently less stiff than the control mixture.

The dynamic modulus data was then utilized to develop mixture master curves for each binder type. Mixture master curves were developed using the specification provided in NCHRP Report 614 "Proposed Standard Practice for Developing Dynamic Modulus Master Curves for Hot-Mix Asphalt Concrete Using the Simple Performance Test System" (59). The master curves at a reference temperature of 15ºC (representative of intermediate temperatures in the northeast of the United States) for all mixtures tested are shown in Figure 9.

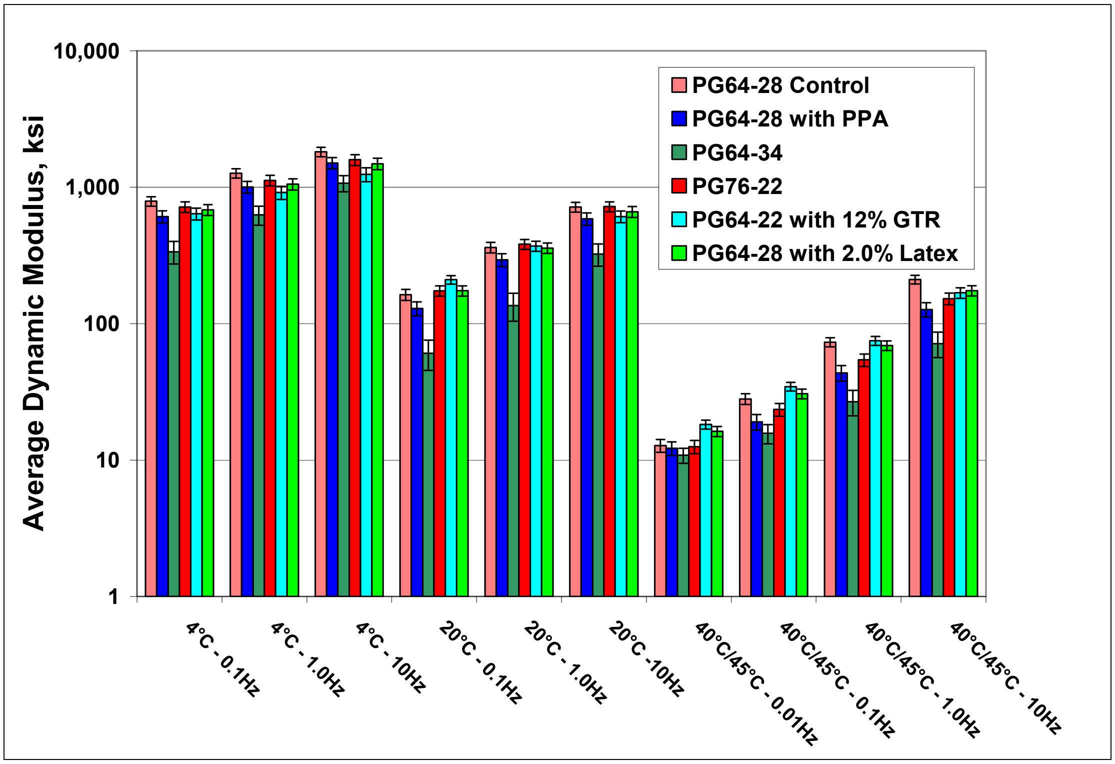

Figure 8. Mixture Dynamic Modulus Data Comparison

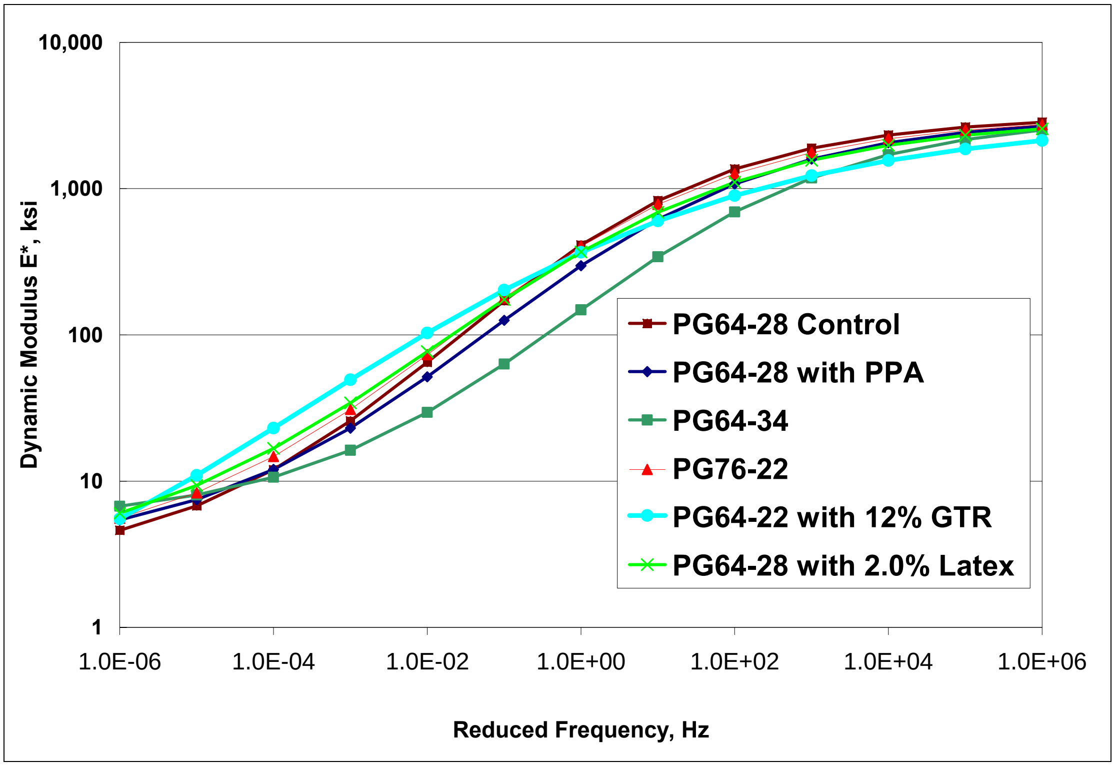

Figure 9. Mixture Master Curves Comparison

The master curves data indicated similar results to the raw dynamic modulus data. For the majority, all mixtures exhibited stiffness similar to the control mixture with the exception of the PG64-34. This trend indicates, for the mixtures tested, that PMA may be utilized without negatively impacting the mixture stiffness. This further indicates that PMA may not negatively affect the low temperature cracking potential of the mixture. To evaluate hypothesis each mixture was tested for thermal cracking resistance using the Indirect Tensile Test (IDT) device.

7.2 Thermal Cracking Analysis using Indirect Tensile Test (IDT) Device Data

In order to understand the impact of the modified binder on the thermal cracking potential of the mixture, each mixture was tested in the in Indirect Tensile Test (IDT) device in accordance with AASHTO T322 "Determining the Creep Compliance and Strength of Hot-Mix Asphalt (HMA) using the Indirect Tensile Test Device."(56). The tensile strength and tensile creep were determined for each mixture and this data was utilized to perform a thermal cracking analysis using the LTStress Microsoft Excel© workbook which was developed at the Northeast Center for Excellence in Pavement Technology (NECEPT).

7.2.1 Specimen Fabrication and Testing

The IDT test specimens were fabricated using the SGC. Each mixture was batched, mixed and short-term aged for four hours in accordance with AASHTO R30 "Mixture Conditioning of Hot Mix Asphalt (HMA)" (56). After aging, specimens (150 mm diameter x 75 mm tall) were compacted in the SGC. These specimens were subsequently cut to the final specimen dimensions of 150 mm in diameter by 38-50 mm tall. Each cut specimen was tested to determine the air voids. The target air void range was 7±1% which correlated to the expected in place density after construction. Three replicates were fabricated for each binder included in this study.

7.2.2 Results

IDT testing was completed in accordance with AASHTO T322 (58). Specimens for all binders were tested at temperatures of 0, -10, and -20°C. The tensile strength and tensile creep were determined for each mixture (at each test temperature) and this data was utilized to perform a thermal cracking analysis using the LTStress Microsoft Excel© workbook. The results of the analysis are shown in Table 6. Generally, the low temperature performance grades of the binders were warmer than the low temperature cracking of the mixtures measured by the IDT. This indicates that the use of the PMA did not increase the low temperature susceptibility of the mixtures tested.

Table 6. LTStress Critical Low Temperature Cracking Temperature Prediction

Binder	LTStress Predicted Critical Cracking Temperature
PG64-28 Control	N/A
PG64-28 + PPA	-41ºC (-41ºF)
PG64-34 SBS	-38ºC (-36ºF)
PG76-22 SBS	-25ºC (-13ºF)
PG64-22 + GTR	N/A
PG64-28 + Latex	-30ºC (-22ºF)

N/A = LTStress prediction could not be made based on data collected.

8.0 Summary and Conclusions

The main objective of this study was to develop thin lift overlay mixtures with polymer modified asphalt for use in New England. As part of this research a comprehensive literature review and internet survey was conducted. Moreover, laboratory testing was conducted on thin lift PMA mixtures in an effort to evaluate their use for New England. Based on all the research conducted under this study, the following conclusions are made:

- The literature review conducted for this study provides an overview of the types of polymer modifiers for asphalt, definitions of thin lift mixture types, definition of surface treatments types, use of thin lift mixtures and surface treatments in New England, tests used in evaluation of thin lift mixtures and surface treatments, comparison of thin lift mixtures and surface treatments, and available methods for timing of application for thin lift mixtures and surface treatments.

- The survey conducted in this study showed the method of selection for using either a surface treatment or lift HMA overlay were decision trees, functional classification of the roadway, existing pavement condition, experience and treatment cost. Moreover, the majority of respondents did not have a methodology to select the appropriate time to apply a strategy.

- Based on the survey, thin lifts are for the majority defined as having thickness less than or equal to 1.5 inches.

- Based on the survey, thin lifts are being utilized to reduce cracking, increase surface friction and provide waterproofing. Surface treatments are being used to prevent oxidation, prevent raveling, reduce cracking, increase surface friction, provide waterproofing and decrease rutting.

- Based on the survey, the cost for thin lift HMA overlay mixtures varied from $3-$8 per square yard. For surface treatments, costs varied from $1-$5 per square yard based on the specific type of treatment.

- Based on the survey, transportation agencies utilized PMA to reduced cracking, reduce rutting, reduce thermal cracking, and extended pavement life. No disadvantages of using polymer modified asphalt were noted.

- From the laboratory testing, the dynamic modulus data indicated that PMA did not necessarily increase the stiffness of the asphalt mixture as compared with the unmodified binder. This indicates that the use of the PMA may not increase the low temperature (thermal) cracking susceptibility of the mixture.

- The laboratory data indicated that the low temperature performance grade of the binders were warmer than the low temperature cracking of the mixtures predicted using IDT measurements. This indicates that the use of the PMA did not increase the low temperature susceptibility of the mixtures tested.

- Based on the laboratory data, PMA is recommended to be utilized for thin lift maintenance mixtures in the New England region. The specific type and properties of the PMA should be investigated on a case by case basis.

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Appendix A: Internet Based Survey

Preventive Maintenance Strategies:
Thin Lift HMA Overlays, Surface Treatments, and Modification

Description and Instructions: This survey is an attempt to better understand the current state of practice with regards to thin lift HMA overlay maintenance mixes and surface treatments. Also, the survey will give comprehension to current methodologies of industry professionals when selecting a preventive maintenance treatment and when to apply it. Please answer the following questions to the best of your ability. If you are unsure of any question leave it blank and continue to the next question. Thank you for your time.

Your Contact Information

Please enter your contact information below. Your name, title and organization are required; your state, email and phone are optional.

Name:

Title:

Organization:

State/Region:

Email:

Phone Number:

Section 1: Preventive Maintenance Strategies

1. Does your agency have a Preventive Maintenance strategy in place? (Please describe)

2. How does your agency decide on whether to use surface treatments or thin lift HMA overlays? (Please describe)

3. Does your agency practice a strategy to determine optimum time for Preventive Maintenance such as NCHRP Report 523 "Optimal Timing of Pavement Preventive Maintenance Treatment Applications"?

- ○ Yes - Please describe:
- ○ No

4. Does your agency use any of the following equipment to determine pavement distresses or failures? (Check all that apply)

- ☐ a. Ground Penetrating Radar
- ☐ b. Falling Weight Deflectometer
- ☐ c. Seismic Property Analyzer
- ☐ d. Profiler
- ☐ e. ARAN/Network Level Vehicle
- ☐ f. Visual Survey
- ☐ g. Other:

5. For the equipment indicated please comment about their purpose for your agency.

6. Does your agency have a method in order to choose different surface treatments or thin lift HMA overlay mixes (Decision trees, formulas, computer software)?

- ○ Yes - Please describe:
- ○ No

Section 2: Thin Lift Overlay Maintenance Mixes

7. How does your agency define a thin lift?

- ○ a. Less than or equal to ½"
- ○ b. Less than or equal to ¾"
- ○ c. Less than or equal to 1"
- ○ d. Less than or equal to 1 ½"
- ○ e. Less than or equal to 2"
- ○ f. Other:

8. Does your agency use or specify any thin lift HMA overlay maintenance mixes?

- ○ Yes
- ○ No

9. If you answered yes to the previous question, what types of mixes does your agency use? Next to each mix selected please fill in traffic volumes for which it would be used. (Check all that apply)

- ☐ a. Dense graded:
- ☐ b. Coarse graded:
- ☐ c. Open Graded Friction Course (OGFC):
- ☐ d. Stone Matrix Asphalt (SMA):
- ☐ e. Sand (fine aggregate) Mix:
- ☐ f. Others:

10. What surface preparation (seal cracks, tack coat, etc) is required for the different types of mixes your agency uses? Also, please list the condition of the roads before each mix would be applied.

Condition of Road	Surface Preparation	Thin Lift Mix Used

11. What distresses does your agency hope to resolve using thin lift HMA overlay maintenance mixes? (Check all that apply)

- ☐ a. Raveling
- ☐ b. Oxidation
- ☐ c. Cracking
- ☐ d. Rutting
- ☐ e. Skid Resistance/Surface Friction
- ☐ f. Waterproofing/Water Infiltration Prevention
- ☐ g. Other:

12. Does your agency use a mix design method when designing thin lift HMA overlay?

- ○ Yes
- ○ No

13. If you answered yes, please name the method (SuperPave, Marshall, etc.) and list the volumetrics your agency is trying to meet. (Please describe)

14. Does your agency use a recipe when designing a thin lift HMA overlay?

- ○ Yes
- ○ No

15. If you answered yes, please list the gradations and binder content. (Please describe)

16. Does your agency use any laboratory tests or equipment when using or designing thin lift HMA overlay mixes? Please list tests or equipment and purposes of each. (Please describe)

17. For the thin lift HMA overlays your agency uses please give any cost information that is available. (Please describe)

18. Have you or your agency noticed any benefits or limitations (performance, cost, etc.) from using thin lift maintenance mixes? (Please describe)

Section 3: Surface Treatments

19. Does your agency use any surface treatments (i.e. microsurfacing, slurry seal, etc.)?

- ○ Yes
- ○ No

20. If you answered yes to the previous question, please select which ones. Next to each mix selected please fill in traffic volumes for which it would be used. (Check all that apply)

- ☐ a. Microsurfacing: _____
- ☐ b. Slurry Seal: _____
- ☐ c. Chip Seal: _____
- ☐ d. Double Chip Seal: _____
- ☐ e. Rubber Chip Seal: _____
- ☐ f. Double Rubber Chip Seal: _____
- ☐ g. Emulsion Chip Seal: _____
- ☐ h. Double Emulsion Chip Seal: _____
- ☐ i. Cape Seal: _____
- ☐ j. Sand Seal: _____
- ☐ k. Fog Seal: _____
- ☐ l. Scrub Seal: _____
- ☐ m. Nova Chip: _____
- ☐ n. Other: _____

21. What surface preparation (seal cracks, tack coat, etc) is required for each different type of surface treatment your agency uses? Also, please list the condition of the roads before each surface treatment would be applied.

Condition of Road	Surface Preparation	Surface Treatment Used

22. What distresses does your agency hope to resolve using surface treatments? (Check all that apply and note the surface treatment used)

- ☐ a. Raveling: _____
- ☐ b. Oxidation: _____
- ☐ c. Cracking: _____
- ☐ d. Rutting: _____
- ☐ e. Skid Resistance/Surface Friction: _____
- ☐ f. Waterproofing/Water Infiltration Prevention: _____
- ☐ g. Other: _____

23. Have you or your agency noticed any benefits or limitations (performance, cost, etc.) from using surface treatments? (Please describe and note the surface treatment)

24. For the surface treatments your agency uses please give any cost information that is available.

25. Does your agency use any equipment or tests when using or designing surface treatments? Please list equipment or tests and purposes of each.

Section 4: Polymer Modified Asphalt

26. Does your agency use any of the following polymers or modified binders for thin lift HMA overlays? (Check all that apply and note the thin lift overlay each is used for)

Polymers

- ☐ a. Styrene-butadiene-styrene (SBS):
- ☐ b. Styrene-butadiene rubber (SBR):
- ☐ c. Crumb Rubber:
- ☐ d. Ethylene Vinyl Acetate (EVA):
- ☐ e. Elvaloy AM:
- ☐ f. Neoprene:
- ☐ g. Other:

Modified Binders

- ☐ h. Styrelf:
- ☐ i. Novophalt:
- ☐ j. Other:

27. Does your agency use any of the following polymers or modified binders for surface treatments? (Check all that apply and note the surface treatment each is used for)

Polymers

- ☐ a. Styrene-butadiene-styrene (SBS):
- ☐ b. Novophalt:
- ☐ c. Crumb Rubber:
- ☐ d. Ethylene Vinyl Acetate (EVA):
- ☐ e. Elvaloy AM:
- ☐ f. Neoprene:
- ☐ g. Other:

Modified Binders

- ☐ h. Styrelf:
- ☐ i. Styrene-butadiene rubber (SBR):
- ☐ j. Other:

28. If your agency is currently using polymer modified asphalt, what is the base PG and what is the target PG (Example: begin with PG 64-28, end with PG 76-34) or does your agency use PG+ Grading Specifications? (Please list)

29. Is there a particular way in which your agency specifies the use of polymer modified asphalt binders? (Check all that apply)

- ☐ a. PG
- ☐ b. Dose
- ☐ c. Other: ________

30. If your agency is using polymer modified asphalts what are the factors for deciding one over the other? (Check all that apply)

- ☐ a. Cost
- ☐ b. Life time
- ☐ c. Workability
- ☐ d. Other: ________

31. Have you or your agency noticed any advantages or disadvantages of using polymer modified asphalt? (Please list and explain)

Submit Your Answers

Appendix B: Internet Based Survey Results

HSRC Highway Sustainability Research Center   UMass Dartmouth

Research Project:

Fix It First: Utilizing the Seismic Property Analyzer and MMLS to Develop Guidelines for the Use of Polymer Modified Thin Lift HMA vs. Surface Treatments

A New England Transportation Consortium (NETC) Sponsored Research Project

Survey Results

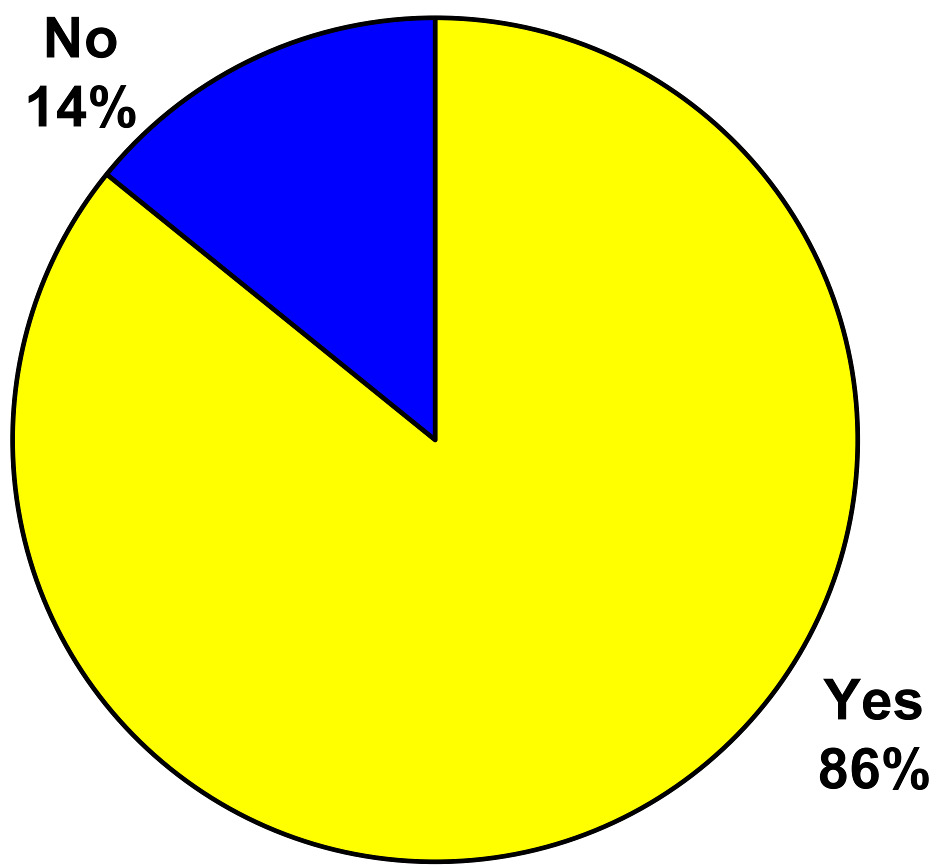
Preventive Maintenance Strategies: Thin Lift HMA Overlays, Surface Treatments and Modification

(Not for Distribution)

Number of Responses Solicited = 155
Number of Responses Received = 14

Response Percentage = 9.0%

Question 1. Does your agency have a Preventive Maintenance strategy in place? (Please describe)



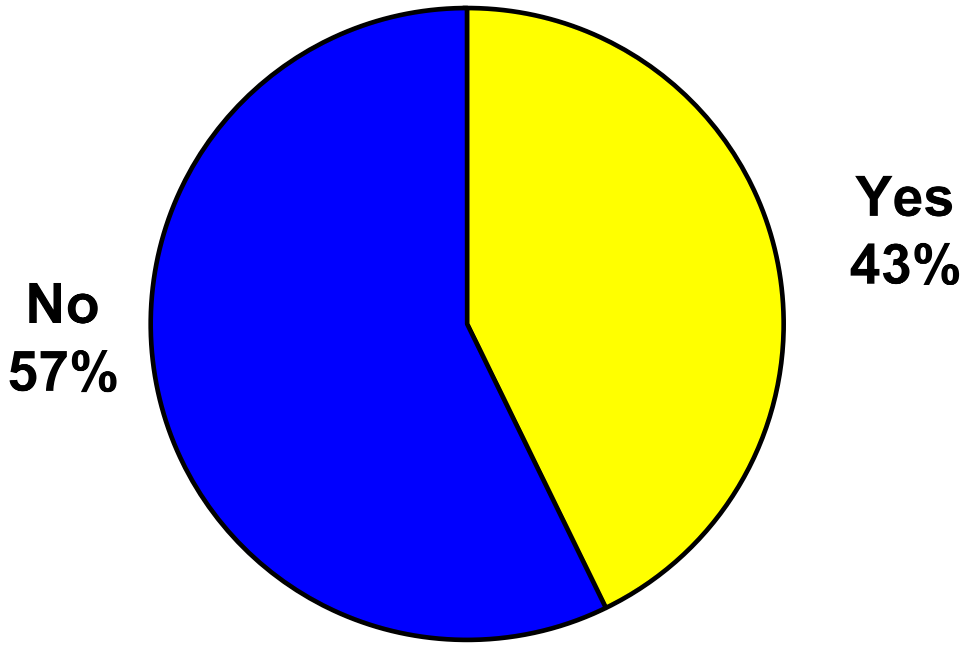
<u>Question 1:</u> Does your agency have a Preventive Maintenance strategy in place? (Please describe)

Respondent #	Response
1	Yes. Annual review of candidate roads to assess their condition. Selection of those most appropriate for crack seal, rubberized asphalt chip seal (RACS), and paver placed elastomeric surface treatment (PPEST).
2	Not written. The District Maintenance Engineers select roads for preventive maintenance treatments.
3	YES, but each of the six Districts have their own approach.
4	Yes. It is subprogram under the statewide pavement preservation program. The Preventive Maintenance Engineer manages the program.
5	YES, Program is decentralized, but fairly well utilized
6	We do not currently have a formal Preventative Maintenance Program in place.
7	Yes, With our pavement management system and maintenance personnel, we have a number of treatments along with the condition of the roadway that we would qualify as preventive maintenance.
8	Yes. We attempt to treat roads in good condition to prevent them from falling into fair and then poor condition. The right treatment to the right road at the right time.
9	Yes, Pavement management system with annual inspections of the Regions of the state.
10	Roads in Nevada are divided into 5 classes based on functional class, ADT, and EWLs. Specified construction and maintenance treatments are based on time and condition surveys.
11	Yes, we have a percentage of our annual budget allocated directly for PM projects.
12	We use a pavement management software based on the Army Corp of Engineers pavement management system.
13	Yes. Basic concept is that good roads cost less and that we have scheduled surface treatments, including rejuvenation, chip seal, slurry seal, open-graded surface courses, dense-graded surface courses and thin overlays. These treatments are time based and treatment type varies with roadway characteristics. Treatment schedules can be adjusted due to road conditions or budget fluctuations.
14	Yes, Caltrans developed maintenance advisory technical guide (MTAG) for both flexible and rigid pavements

<u>Question 2:</u> How does your agency decide on whether to use surface treatments or thin lift HMA overlays? (Please describe)

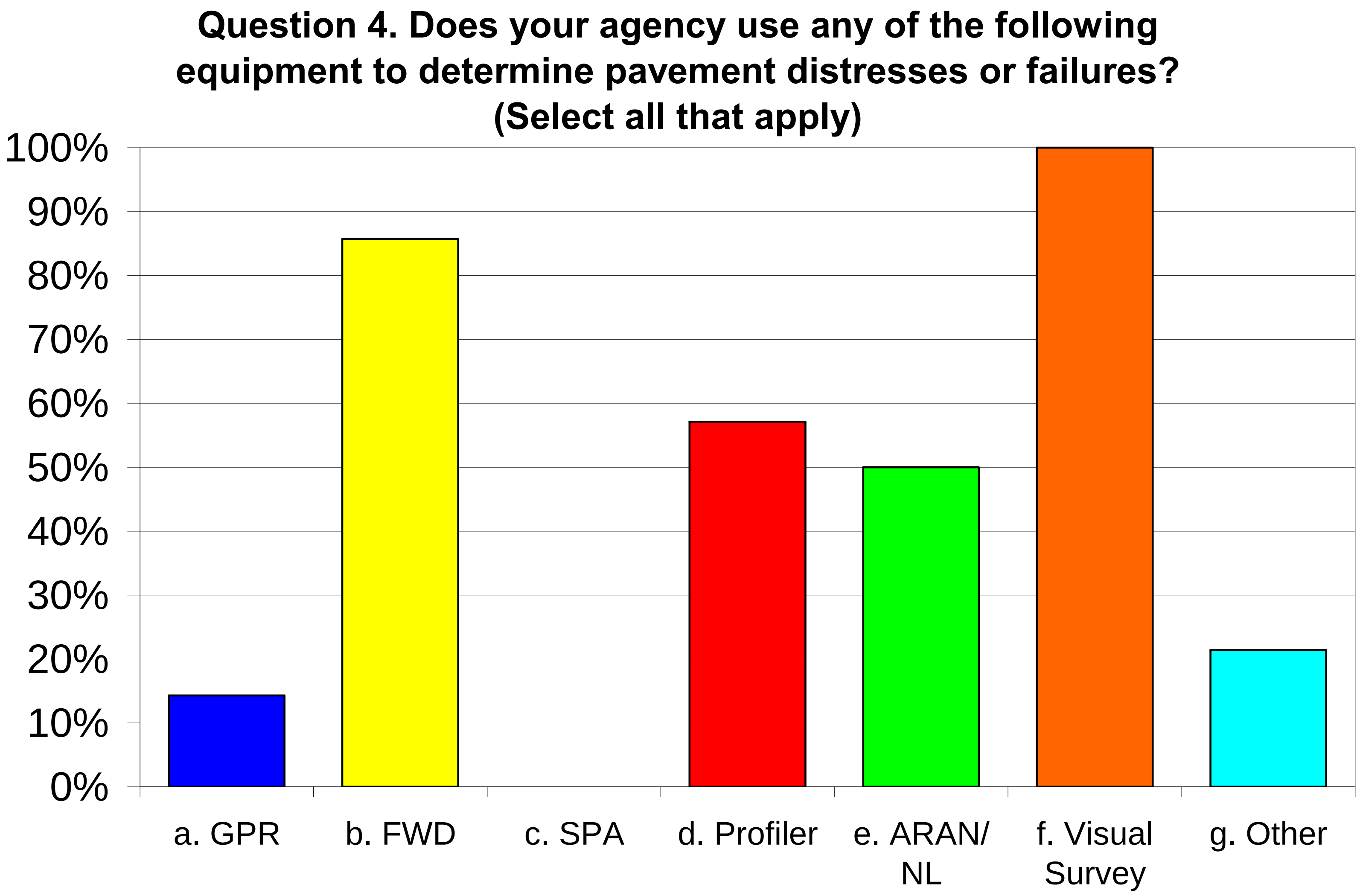
Respondent #	Response
1	Decision tree--primarily use thin lift overlay (PPEST) in urban areas, surface treatment (RACS) elsewhere.
2	High volume roads get the thicker HMA treatments.
3	Surface treatments are not commonly used on State routes in the last 6 years (management policy). Thin lift HMA is used to cover severe distress (band-aid) until a project can be scheduled.
4	Test sections. Cost-benefit analysis.
5	Age, distress
6	Engineering Experience
7	First, we use our pavement management system to identify the roadway in good or fair condition. Second, we determine the functional classification of the roadway to help decide the treatment. The last step, we look at the budget for the most cost effective treatment.
8	We use Chapter 10 Preventive Maintenance of our Comprehensive Pavement Design Manual to select treatments. Several of the pavement preservation treatments have the same wants and warrants, so the decision to use one over the other can be personal preference, availability of local contractors and/or materials, past performance, etc.
9	Based on existing condition of the surface
10	Nevada does not place thin lift HMA. The minimum thickness of overlays in Nevada is 2 inches.
11	We use a Pavement Optimization Program (POP) to determine needs and candidates. All 10,000 miles of state highways are digital video recorded, data collects (faulting, rutting, cracking...) and loaded into POP every year. Once a candidate is selected based on POP, and then the proper strategy is selected.
12	If a road's condition were still good enough to use a thin HMA overlay we would not have the money to pave it. We have to focus our money on the roads that are nearing total failure before we can afford to spend on decent roadways. The cost differential is not that much and experienced contractors using the technology are few and far between.
13	Thin lift HMAs are typically left for structural improvements when structural or deformation distresses are present or necessary.
14	primarily based on pavement condition, environment, travel level, and cost

Question 3. Does your agency practice a strategy to determine optimum time for Preventive Maintenance such as NCHRP Report 523 "Optimal Timing of Pavement Preventive Maintenance Treatment Applications"?



<u>Question 3:</u> Does your agency practice a strategy to determine optimum time for Preventive Maintenance such as NCHRP Report 523 "Optimal Timing of Pavement Preventive Maintenance Treatment Applications"?

Respondent #	Response
1	No
2	No
3	No
4	Yes Comment: Based on own experience and performance data and others.
5	Yes
6	No
7	Yes Comment: We are in the initial phases of using the report to help us.
8	No
9	No
10	Yes, see answer Question 1.
11	Yes, For interstates & expressways a PM is automatically programmed after each reconstruction or resurfacing project.
12	No
13	Yes, Delphi survey (Polling those that design and maintain the roads)
14	No, Caltrans is in the process of developing guidelines for strategy selection


Question 4. Does your agency use any of the following equipment to determine pavement distresses or failures? (Select all that apply)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
a. GPR
b. FWD
c. SPA
d. Profiler
e. ARAN/ NL
f. Visual Survey
g. Other

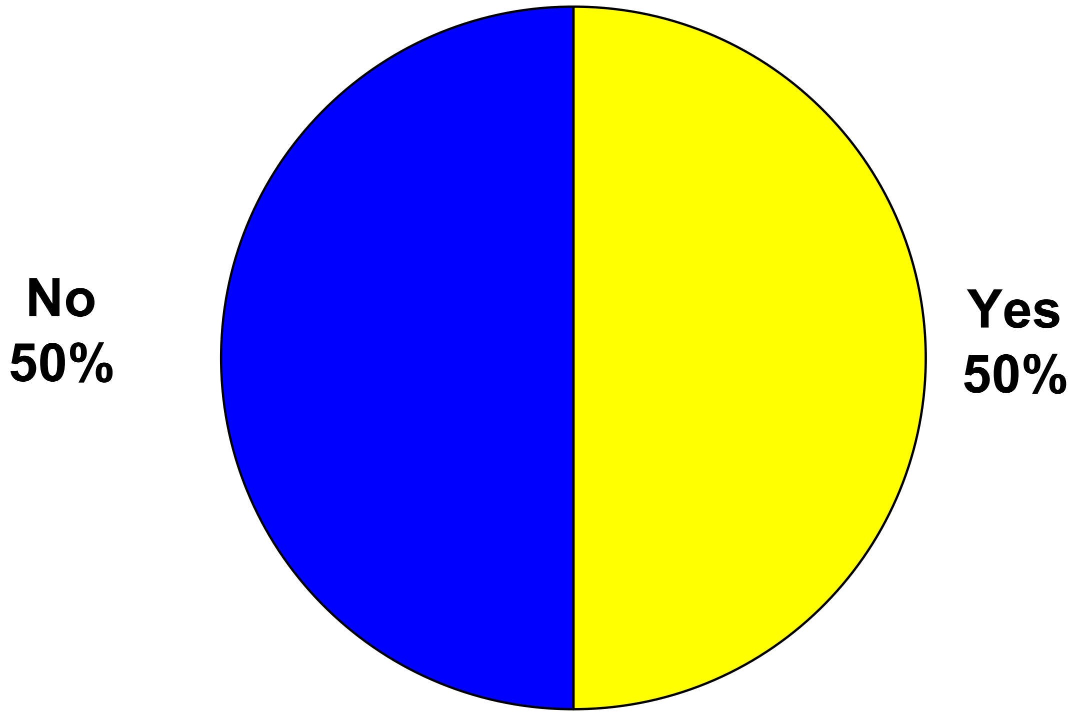
<u>Question 4:</u> Does your agency use any of the following equipment to determine pavement distresses or failures? (Other responses)

Respondent #	Response
1	-
2	-
3	-
4	Other: friction tester
5	-
6	-
7	-
8	-
9	-
10	-
11	-
12	-
13	Other: looking at automated crack recognition process. Also used a lock-wheel skid trailer.
14	-

<u>Question 5:</u> For the equipment indicated in Question 4, please comment about their purpose for your agency?

Respondent #	Response
1	FWD: Structural ARAN: Network survey Visual: Pavement Preservation
2	e. Ride, rutting, surface distress. f. Final treatment selection
3	all are used for network level and project level analysis
4	Friction, pavement age and visual survey have more to do with preventive maintenance than any other testing.
5	-
6	The Profiler and Visual Survey are completed every two years for our Pavement Management System. The Falling Weight Deflectometer is performed on a project by project basis.
7	FWD helps us determine the current condition of the pavement structure. The profiler gives us the surface condition. The network level vehicle helps us determine the rate of deterioration. The visual survey helps us verify that we have the conditions noted from the network level vehicle.
8	FWD has limited use, mostly upon request ARAN used for network survey every two years Visual survey performed annually
9	FWD general use strengths and forensic investigations Pathways Pavement management system use Profiler for specification on construction Visual survey to supplement Pathway van data
10	The Falling Weight Deflectometer is used to verify proposed strategies for reconstruction. Visual inspections are made to determine if the condition of the road falls within the initial repair strategies.
11	FWD is used for determining Pavement & Subgrade modulus. This very beneficial for our in-place recycling strategies. Cores are used to determine lower lift issues such as stripping and the material is used for mix designs in recycling strategies. Visual survey is part of POP program for rating the pavements. This is necessary for PM projects and rehab projects
12	We have inspected all the roads in Amherst in one year and placed them on a diminishing condition model which we calibrate by re-inspecting 10% of the roadways each year.
13	FWD is a 4 year cycle at system level, and frequently used at project level. No longer included in our system condition index due to time between evaluations. The profiler, skid and visual distress surveys are done on a yearly or bi-yearly basis depending on road location.
14	b-structural evaluation & rehab design d-measurement of profile f-pavement condition survey for maintenance & structural analysis

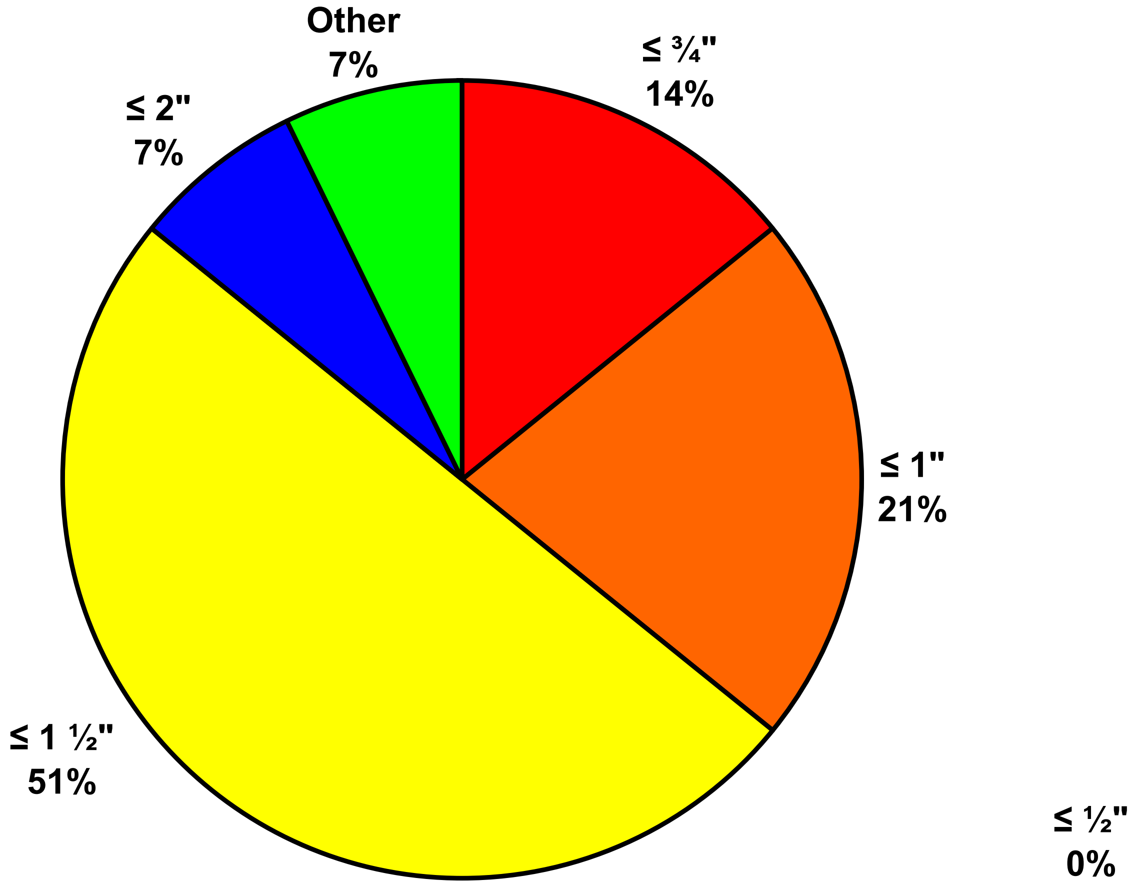
Question 6. Does your agency have a method in order to choose different surface treatments or thin lift HMA overlay mixes (Decision trees, formulas, computer software)?



<u>Question 6:</u> Does your agency have a method in order to choose different surface treatments or thin lift HMA overlay mixes (Decision trees, formulas, computer software)?

Respondent #	Response
1	No
2	No
3	No
4	Yes Comment: Case by case treatments and Decision trees, formulas, computer software.
5	Yes Comment: Decision Tree
6	No
7	Yes Comment: We base our decision on current distresses and when we can do the work
8	No
9	No
10	Yes, Flow chart by road classification and visual confirmation.
11	Yes, A decision tree along with the POP software imitate. Then District Engineers, Maintenance Supt and Pavement section make final decisions.
12	Yes, Cartegraph Pavement Management
13	Yes, Surface treatments are categorized into basic (chips, slurries) or premium (hot applied chip, ogsc, etc.) and they are applied to roads based on AADT and condition.
14	No

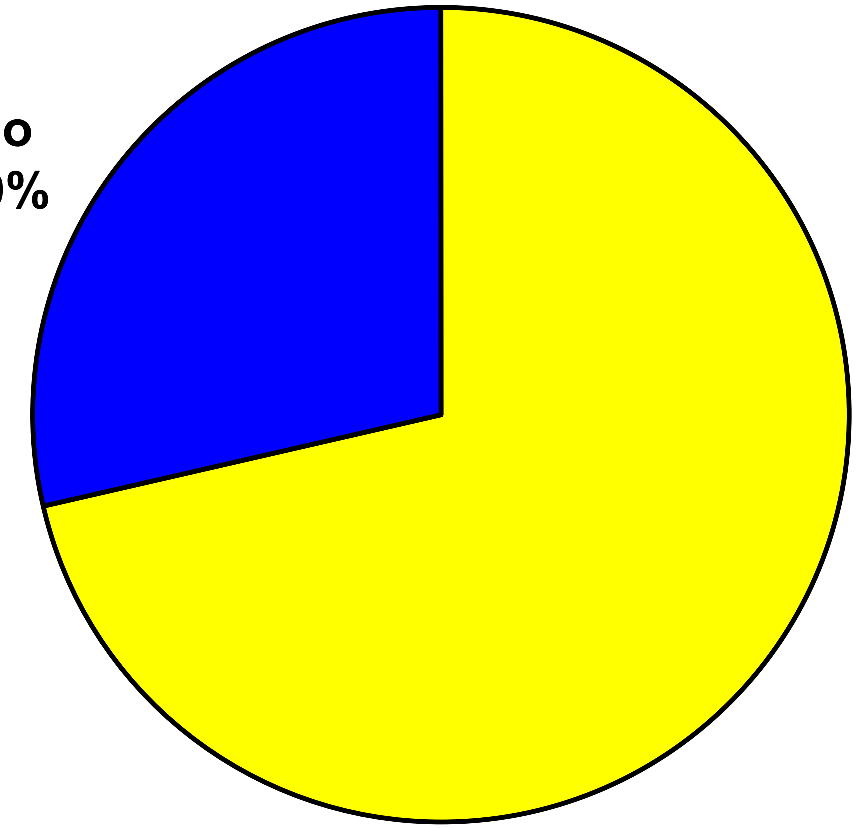
Question 7. How does your agency define a thin lift?

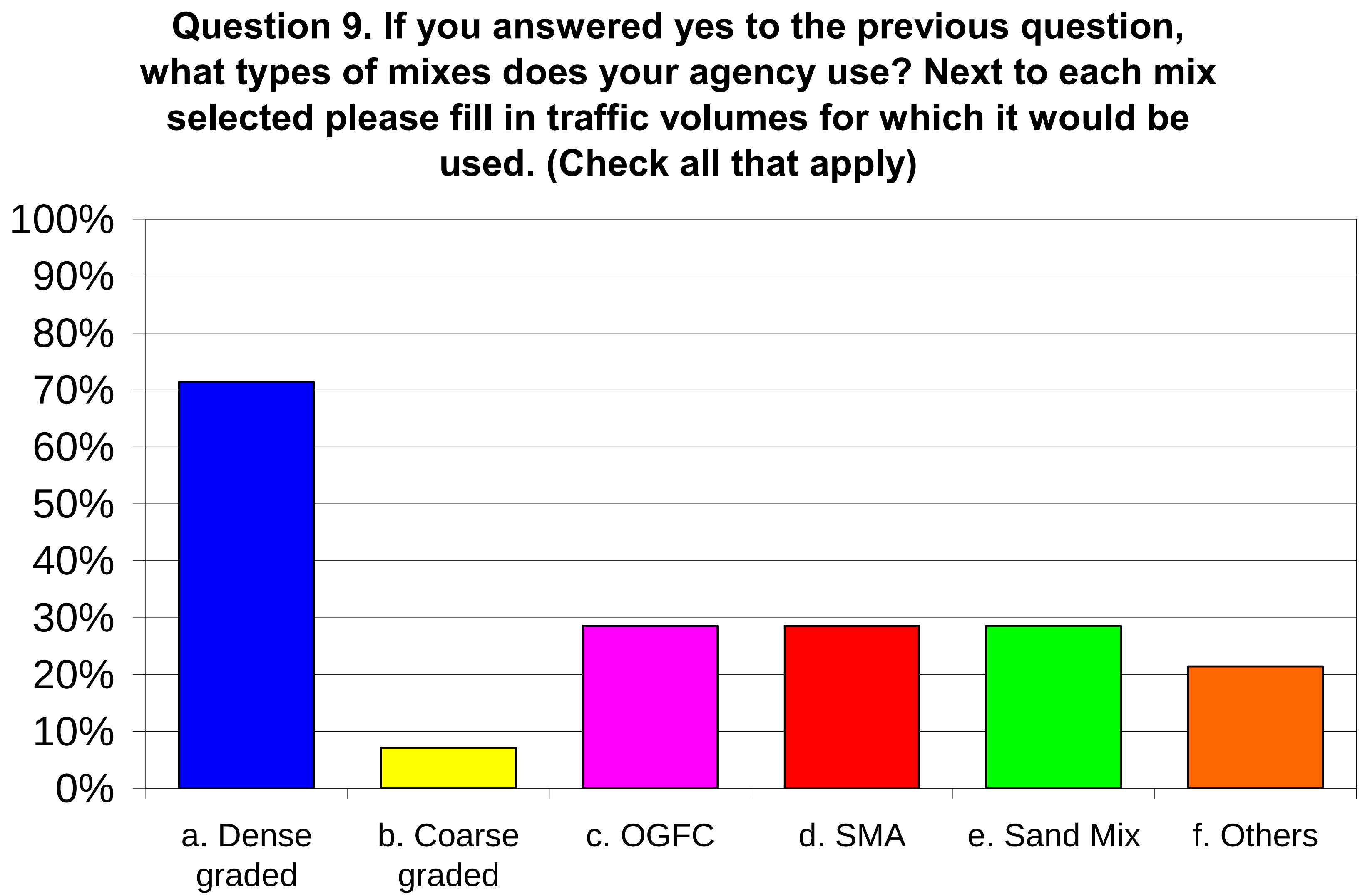


<u>Question 7:</u> How does your agency define a thin lift?

Respondent #	Response
1	-
2	-
3	-
4	-
5	-
6	-
7	Other: less than 2 inches
8	-
9	-
10	No description
11	-
12	-
13	-
14	-

Question 8. Does your agency use or specify any thin lift HMA overlay maintenance mixes?




Question 9. If you answered yes to the previous question, what types of mixes does your agency use? Next to each mix selected please fill in traffic volumes for which it would be used. (Check all that apply)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
a. Dense graded
b. Coarse graded
c. OGFC
d. SMA
e. Sand Mix
f. Others

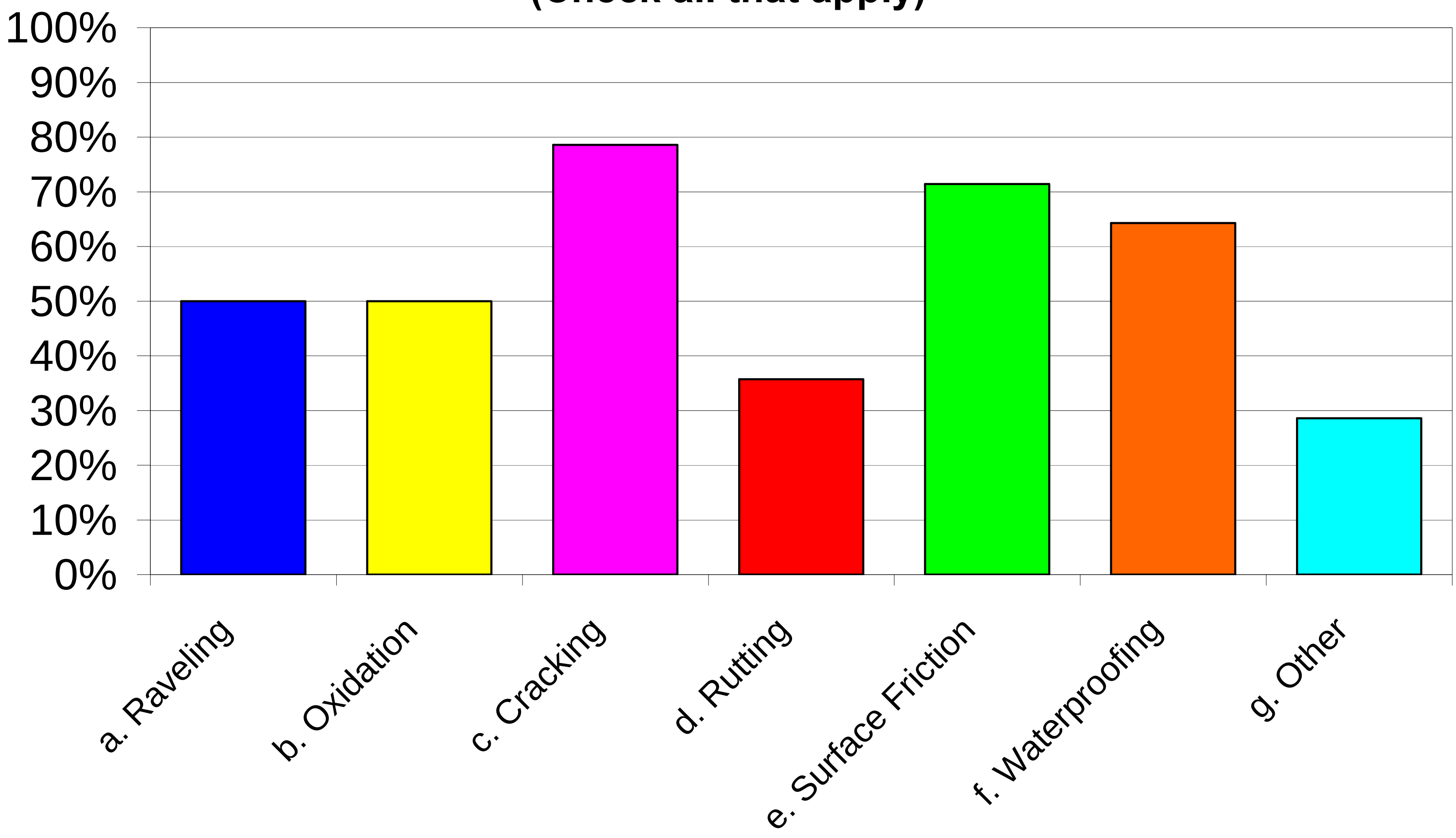
<u>Question 9:</u> If you answered yes to the previous question, what types of mixes does your agency use? Next to each mix selected please fill in traffic volumes for which it would be used. (Check all that apply)

Respondent #	Response
1	-
2	-
3	-
4	-
5	f. Ultra thin bonded wear
6	a. Superpave Mix c. A project will be completed this summer. d. One project completed to date. e. 4.75 mm mix
7	a. Any volume d. High volume e. Low to moderate volume
8	a. All f. 6.3 mm HMA
9	a. All d. >3 million ESALs e. Lower volume
10	-
11	a. More dependent on existing pavement. Typically don't use 1" strategy for roadways with over 6,000 ADT.
12	a. MHD Top Course
13	-
14	-

<u>Question 10:</u> What surface preparation (seal cracks, tack coat, etc) is required for the different types of mixes your agency uses? Also, please list the condition of the roads before each mix would be applied.

	Response		
Respondent #	**Condition**	**Surface Prep**	**Thin Lift**
1	Structurally sound	Shim if necessary, seal cracks, tack coat.	PPEST
2	good to poor	tack coat	3/4
	good to poor; low volume	tack coat	3/8" sand mix
3	fatigue cracking	tack coat	1/2-inch HMA
4	seal cracks	clean	ACFC or ARACFC
5	good	none	chip seal
	fair	crack seal	chip seal
	poor	patch/crack repair	micro/thin lift
6	-	-	-
7	Limited base failures	none	Dense, SMA, sand
	low raveling	none	same as above
	Mod. Longitudinal and trans cracking	none	same as above
8	Good	Clean pavement, crack prep, abrade or remove pave markings, patch holes	dense & 6.3 mm HMA
9	3-5 yr old pavement	crack seal prior year	surface treatment
	oxidized old surface	fine mix over surface 0.5"	thin lift overlay 1.5"
	depressed joints	joint treatment	thin overlay 1.5"
	no ruts but higher traffic	macro surfacing in ruts	micro surfacing
10	-	-	-
11	Good	minimal prep, tack coat	we call it a RLC, regular leveling course (3/16" gradation)
	poor-good	matching tons & tack coat	RLC
	poor	would probably not put thin lift on this type of roadway. Not effect cost benefit.	
12	pot holes, low spots	binder leveling course applied	1.5"
	Existing asphalt in good condition	Tack coat is applied to the entire roadway	1.5"
13	Large Cracks	Seal/fill	all
	Rutting	mill	all
14	Thin lift mix is primarily used for pavement with a sound structural capacity		
	Surface preparation typically involves crack sealing, tack, coat, localized repair including digout of severely distressed pavement		

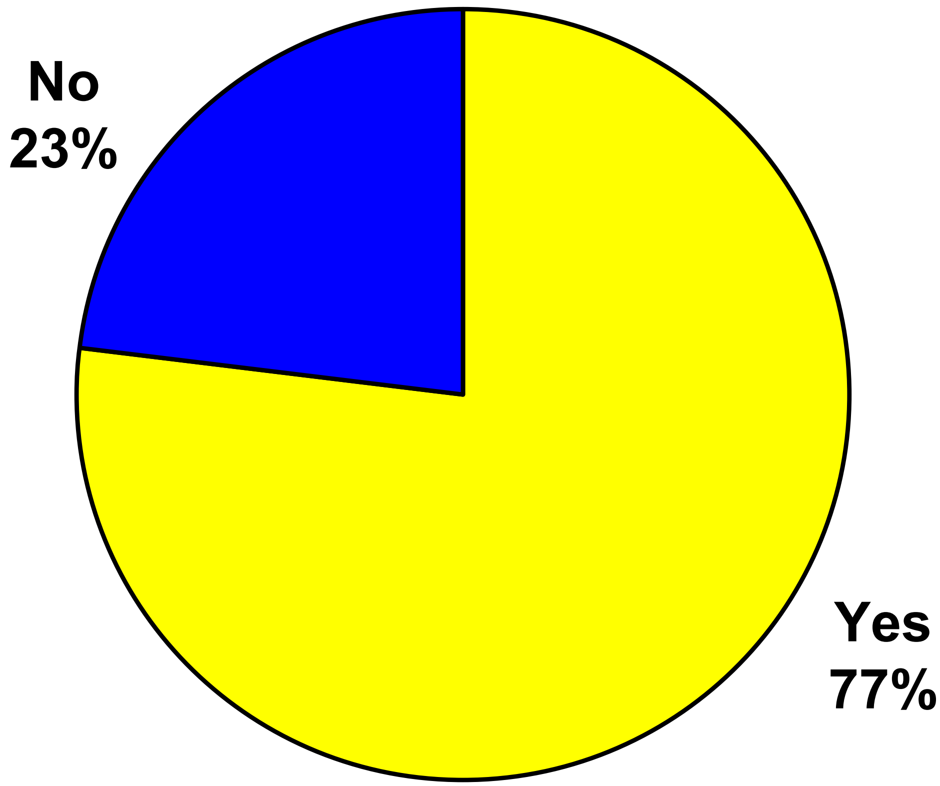
Question 11. What distresses does your agency hope to resolve using thin lift HMA overlay maintenance mixes? (Check all that apply)



<u>Question 11:</u> What distresses does your agency hope to resolve using thin lift HMA overlay maintenance mixes? (Check all that apply)

Respondent #	Response
1	-
2	-
3	Other: this does not RESOLVE the distresses
4	Other: Noise reduction
5	Other: ride improvement
6	-
7	-
8	-
9	-
10	-
11	Complaint phone calls
12	-
13	c. including reflective with rubberized AC
14	-

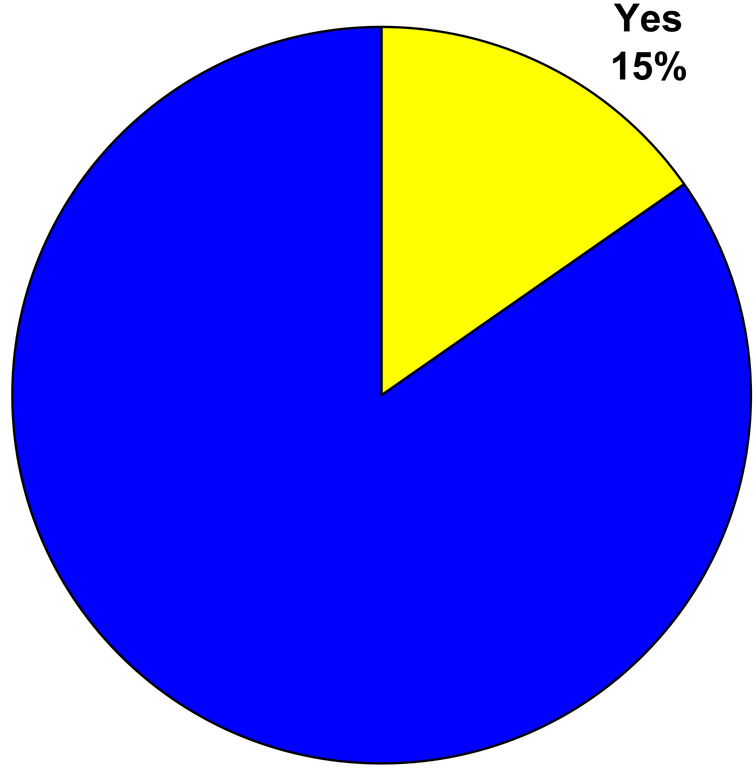
Question 12. Does your agency use a mix design method when designing thin lift HMA overlay?



<u>Question 13:</u> If you answered yes, please name the method (SuperPave, Marshall, etc.) and list the volumetrics your agency is trying to meet. (Please describe)

Respondent #	Response
1	Marshall: Voids: 4-6% VMA: 18% minimum
2	Superpave volumetrics depends on traffic level
3	ADOT stored spec.411ACFMS - ASPHALTIC CONCRETE FRICTION COURSE (MISCELLANEOUS)
4	superpave
5	Super Pave Air Voids - 4% VMA - Depends on mix size VFA - For 4.75 mm mixes - depends on traffic level Dust to binder ratio.
6	Superpave. The design VMA will vary based on the nominal maximum aggregate size and the target air voids. The design air voids for our dense graded mixes is between 3.5 and 4.5 percent. The design air voids for our SMA mixes is between 3.0 and 4.0 percent. The design VFA is from 65 to 80 percent.
7	Superpave - 3.5% air voids
8	Marshall or Gyratory
9	Superpave FAA 45 50 gyrations with 4% voids, optimum binder content (we pay for binder separately on all mixes) VMA 16% VFA 72-78% 3/16" gradation band
10	Modified Superpave, using 12.5 mm nominal aggregate.
11	Hveem, 3-5% AV typical, also depends on environment: e,g coastal vs desert
12	Marshall: Voids: 4-6% VMA: 18% minimum
13	Superpave volumetrics depends on traffic level
14	ADOT stored spec.411ACFMS - ASPHALTIC CONCRETE FRICTION COURSE (MISCELLANEOUS)

Question 14. Does your agency use a recipe when designing a thin lift HMA overlay?



<u>Question 15:</u> If you answered yes to Question 14, please list the gradations and binder content. (Please describe)

Respondent #	Response
1	-
2	sand mix; #4 99 - 100 passing AC 7.0% Avg #8 76 - 93 " #16 55 - 74 " #30 34 - 55 " #50 17 - 35 " #100 6 - 15 " #200 2 - 6 " 3/8 Mix 3/8" 95 - 100 passing AC 6.7% Avg #4 70 - 84 " #8 54 - 65 " #16 35 - 51 " #30 20 - 36 " #50 10 - 20 " #100 5 - 11 " #200 2 - 6 "
3	-
4	See the spec.
5	-
6	-
7	-
8	-
9	-
10	-
11	-
12	-
13	-
14	-

<u>Question 16:</u> If you answered yes to Question 14, please list the gradations and binder content. (Please describe)

Respondent #	Response
1	Marshall test equipment Moisture sensitivity test equipment (AASHTO T-283)
2	No
3	standard HMA mix design equipment and procedures (by contractor)
4	See the spec.
5	Standard Superpave process
6	Super Pave Gyratory Compactor Marshall Breaking Press - Use to determine indirect tensile strength - look for the presence of stripping Fine Aggregate Angularity Asphalt Pavement Analyzer
7	Yes, We use the standard Superpave equipment.
8	standard Superpave equipment
9	APA to test rutting on all mixes
10	-
11	Yes, standard Superpave testing
12	-
13	Superpave requirements, including Gyratory compactor and full-range binder testing. Also use the Hamburg Wheel Tracker for moisture damage and rut resistance.
14	-

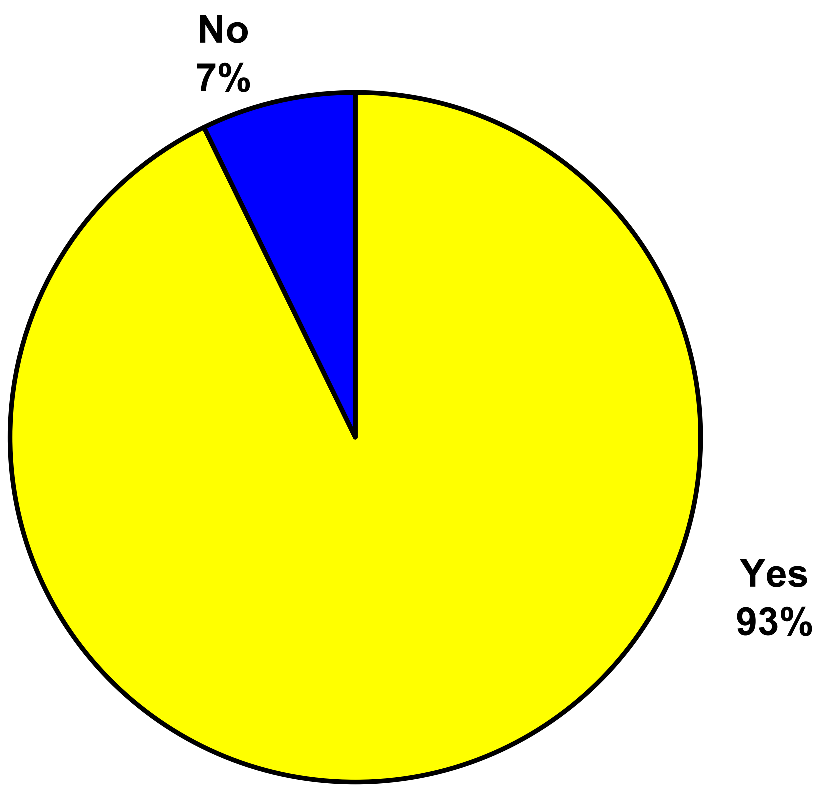
<u>Question 17:</u> For the thin lift HMA overlays your agency uses please give any cost information that is available. (Please describe)

Respondent #	Response
1	2006: $7.40/SY (PPEST)
2	-
3	not available
4	ARACFC - ACFC 3-5 $/SY
5	varies greatly
6	-
7	Sand mixes are about $70/ton. The dense graded mixes are about $60/ton. The SMA mixes are about $65/ton. All of these prices will vary based on quantity and location.
8	$55 to $75 per metric ton in place depending on project size and location - price includes maintenance and protection of traffic
9	-
10	-
11	For about $60,000 per mile (24' wide), but varies on length and location.
12	x
13	$5 to $8 per SY, in place depending on project location and size. Binder issues in the past year have created greater variability in those numbers.
14	thin (30 mm) HMA $6-10/sq yd

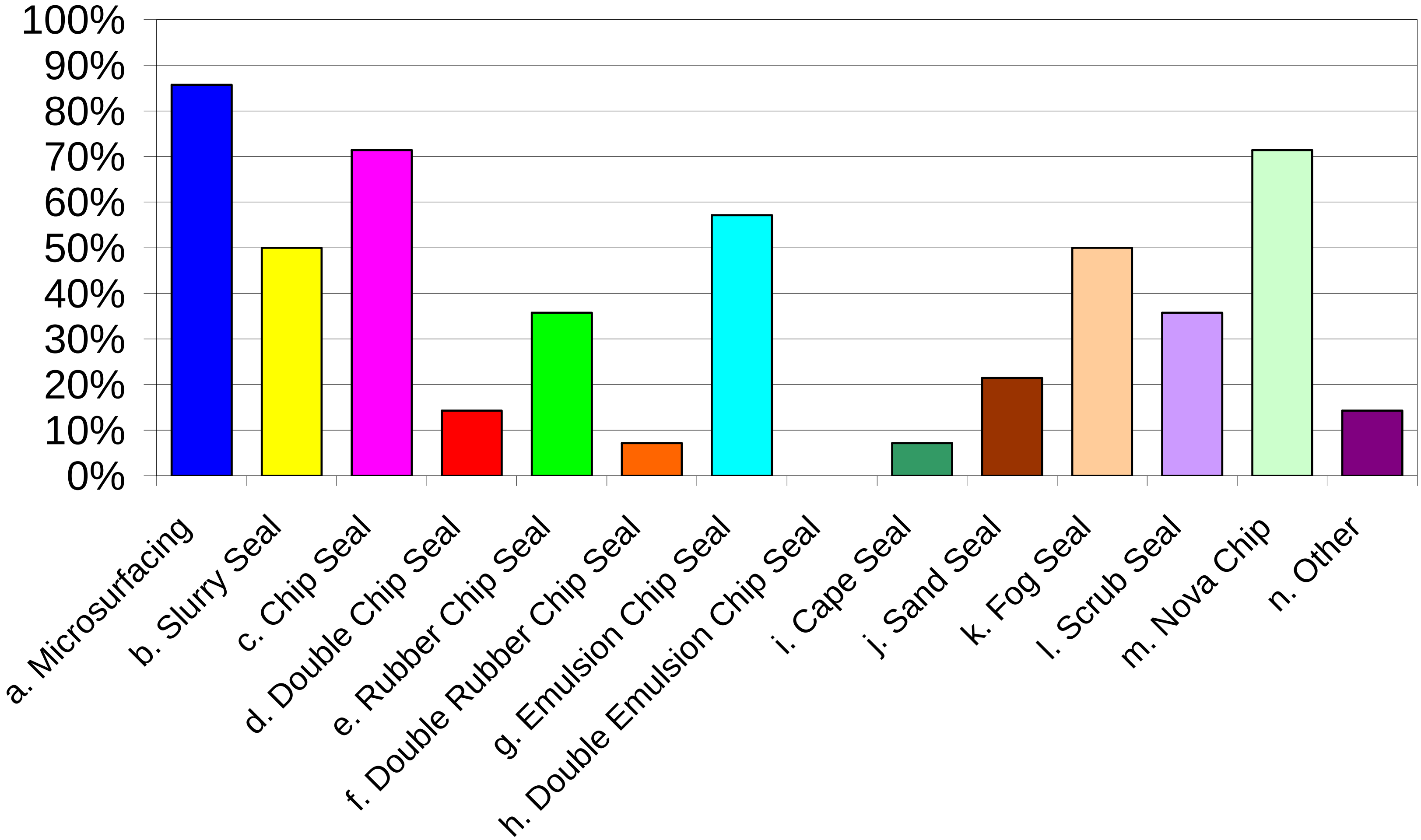
<u>Question 18:</u> Have you or your agency noticed any benefits or limitations (performance, cost, etc.) from using thin lift maintenance mixes? (Please describe)

Respondent #	Response
1	More resistant to cracking than an overlay of conventional mix.
2	Pavements stay smoother and crack less with routine overlays.
3	Thin lift HMA does not generally fix any distress, it simply protects the pavement against severe deterioration
4	Benefits: Better skid resistance. Noise reduction, Life extension and smooth surface. Construction window is narrow.
5	limitation = early crack reflectance , benefit = improved ride
6	-
7	At this time, we have not gathered all the data to make a decision on our current practice and procedures.
8	Pavement preservation - addresses all the distresses indicated in Question 11.
9	-
10	-
11	Thin lifts have done well, but are not used vary often. Overall we use surface treatments quite a bit more often.
12	Any and all surface cracks reflect through in less than a year which then requires crack sealing. It's really just a waste of money that could be spent reconstructing roadways that are in really bad shape.
13	Have seen good control of system condition by using maintenance mixes, however, limitations are in areas of ride and placement. Our thin lifts are compacted to a target of 92.5% (1% less than our typical paving mixes).
14	Rubberized hot asphalt mix typically exhibits much improved resistance to reflective cracking. on a small size job the cost is generally higher then conventional, however, when placed in thin lift the cost could be lower

Question 19. Does your agency use any surface treatments (i.e. microsurfacing, slurry seal, etc.)?



Question 20. If you answered yes to the previous question, please select which ones. Next to each mix selected please fill in traffic volumes for which it would be used. (Check all that apply)

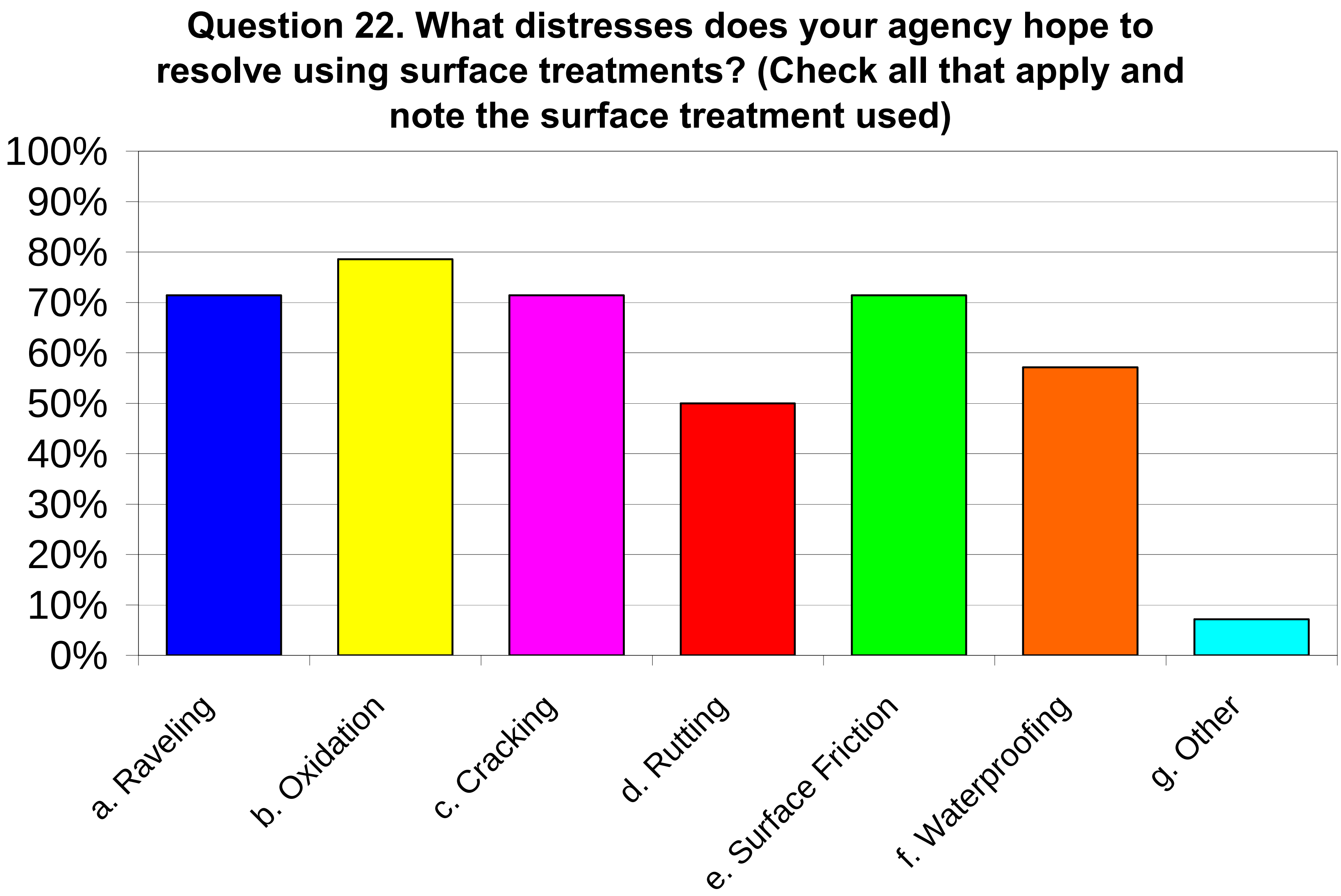


<u>Question 20:</u> If you answered yes to the previous question, please select which ones. Next to each mix selected please fill in traffic volumes for which it would be used.

Respondent #	Response
1	e. Traffic volume not specified.
2	-
3	a. all traffic b. all traffic m. high traffic
4	a. Medium to low traffic b. Medium to low traffic c. Medium to low traffic d. Medium to low traffic j. Medium to low traffic k. Medium to low traffic m. Medium to low traffic
5	a. >2000 c. none g. none k. shoulders m. higher volume
6	-
7	a. all volumes b. low to moderate volume c. low volume j. low volume m. all volumes
8	a. all b. less than 4000 AADT c. less than 2000 AADT e. less than 10,000 AADT g. less than 2000 AADT k. shoulders m. all
9	a. all c. Surface Treatments g. >1 million ESALs k. over most seals m. >3 million ESALs
10	-
11	a. all volumes c. all volumes, except interstates g. all volumes, except interstates k. all volumes
12	--
13	a. High b. Medium - Urban c. Medium - Rural g. Medium - Rural k. any m. High n. Rejuventation - Any
14	-

Question 21: What surface preparation (seal cracks, tack coat, etc) is required for each different type of surface treatment your agency uses? Also, please list the condition of the roads before each surface treatment would be applied.

	Response		
Respondent #	**Condition**	**Surface Prep**	**Surface Treatment Used**
1	Structurally sound	Shim if necessary, seal cracks.	RACS
2	good condition; will address rutting	crack seal & tack	microsurfacing
	good to medium condition	none	nova
	good to poor condition	none	rubber chip seal
3	fatigue cracking	tack coat	1/2-inch HMA
	surface aging	none	microsurface or novachip
	rutting	none	slurry level
	transverse crack roll-down	none	slurry level
4	Fair condition and low skid resistance	clear	all the selected
5	good (SAME AS OTHER)	none	chip seal
	fair	crack seal	chip seal
	poor	patch/crack repair	micro/thin lift
6	-	-	-
7	slight raveling	none	all listed
	minor long. and trans. cracking	none	all listed
8	Good	Clean pavement, crack prep, abrade or remove pave markings, patch holes	each indicated treatment in Question 20
9	same as above	-	-
10	Large Block cracking	Crack seal	chip seal
	Block cracking	scrub seal	chip seal following year
	minor raveling		fog seal
	alligator cracking	composite base and surface removal place base and HMA	double chip seal
	cracking, rutting, severe raveling	cold-in-place recycle	double chip seal
11	3-5 years old	crack seal	fog seal
	8-10 years old	crack seal	chip or gavel seal
12	-	-	-
13	Moderate Cracks	fill/seal	all
14	raveling		fog seal
	oxidized surface		rejuvenating agent
	cracking	seal cracks	rubber ship seal, slurry seal
	cracking with minor rutting	seal cracks	microsurfacing, thin overlay


Question 22. What distresses does your agency hope to resolve using surface treatments? (Check all that apply and note the surface treatment used)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
a. Raveling
b. Oxidation
c. Cracking
d. Rutting
e. Surface Friction
f. Waterproofing
g. Other

<u>Question 22:</u> What distresses does your agency hope to resolve using surface treatments? (Check all that apply and note the surface treatment used)

Respondent #	Response
1	a. RACS b. RACS
2	a. all b. all c. all d. microsurfacing e. all f. all
3	-
4	g. flushing
5	-
6	-
7	a. all listed b. all listed e. microsurfacing
8	-
9	b. chip seals d. micro surfacing e. all types
10	-
11	-
12	-
13	a. all b. all c. all d. Micro e. all f. all
14	a. fog seal b. rejuventating agent c. scrub seal, slurry seal, AR chip seal, RAC d. micro for minor rutting e. slurry/micro, AR chip seal, RAC

<u>Question 23:</u> Have you or your agency noticed any benefits or limitations (performance, cost, etc.) from using surface treatments? (Please describe and note the surface treatment)

Respondent #	Response
1	RACS is most resistant to cracking and has best skid resistance of any treatment.
2	Temperature limitations with microsurfacing and chip seals. Chip seals have not held up on roads that frost heavy significantly in the winter due to snow plow damage.
3	maintenance treatments generally extend pavement service life 4-6 years
4	Extend pavement life and improve surface performance.
5	pavement life extension
6	-
7	At this time, we have not gathered all the data to make a decision on our current practice and procedures.
8	Pavement preservation - addresses all the distresses indicated in Question 22.
9	-
10	The benefits of surface treatments are extended pavement life and reduced construction costs.
11	Fog Seals only last about 1-3 yrs Gravel coats last 3+ Chip seals last 5+ Crack sealing 5-8years
12	
13	Overall program has led to overall system upkeep. Limitations are in having experienced personnel to know when to apply which treatment based on road conditions, etc.
14	Surface treatments generally improve pavement surface condition and delay need for immediate rehabilitation. Some treatments, such as AR chip seals, RAC, may provide 4-10 years of additional life depending on the existing pavement condition and level of traffic

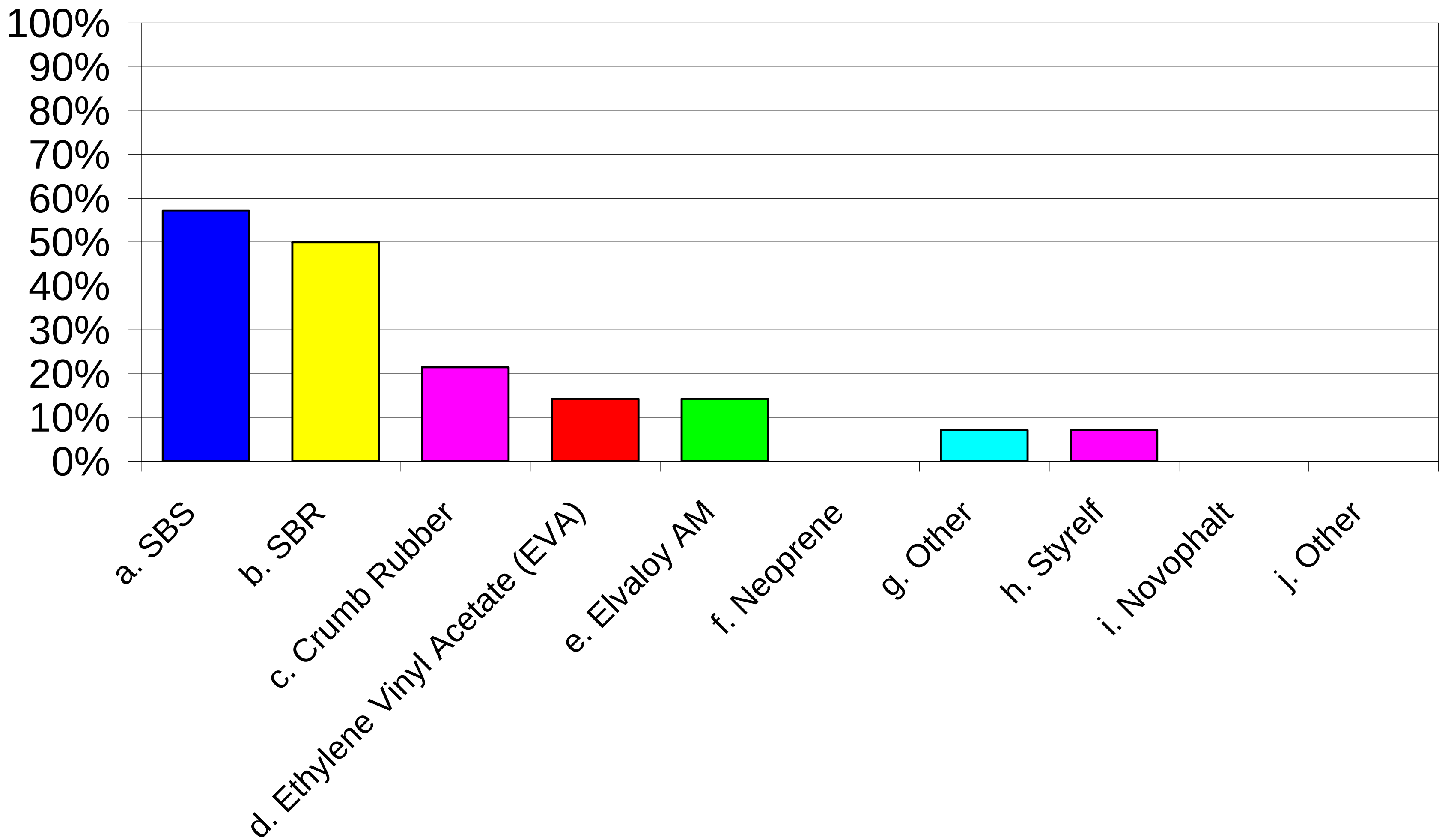
<u>Question 24:</u> For the surface treatments your agency uses please give any cost information that is available.

Respondent #	Response
1	2006: $3.34/SY (RACS)
2	-
3	not available
4	2- 6 $/SY. Costs are going up quickly in recent years. Hard to tell accurate numbers.
5	varies by area/treatment/traffic
6	-
7	Cost data is too variable for a reasonable list.
8	$1.25 /sm for chip seal $1.75 /sm for slurry seal $4.50 /sm for rubber chip seal $4.00 /sm for microsurfacing $4.50 /sm for novachip All costs include Maintenance & Protection of Traffic
9	-
10	Chip seals (done by state forces) $0.91 per sq yard. Fog seals $0.55 per sq yard Scrub seals $1.35 per sq yard. Microsurfacing $3.75 per Sq yard
11	All costs for 24' wide Gravel Coats $13,000 / mile Chip sealing $25,000 / mile Fog Seal $5,000 / mile Crack Sealing $6,000 / mile Microsurfacing $50,000 / mile
12	-
13	Typical surface treatments run $1.5 to $2 per SY, in place. Micros are $3 or so. Novachip has been around $7.
14	AR ship seals $4-5/ sq yd, Thin HMA (30mm) $6-10/sq yd Slurry seals $1.60-2.60/sq yd depending on job size

<u>Question 25:</u> Does your agency use any equipment or tests when using or designing surface treatments? Please list equipment or tests and purposes of each.

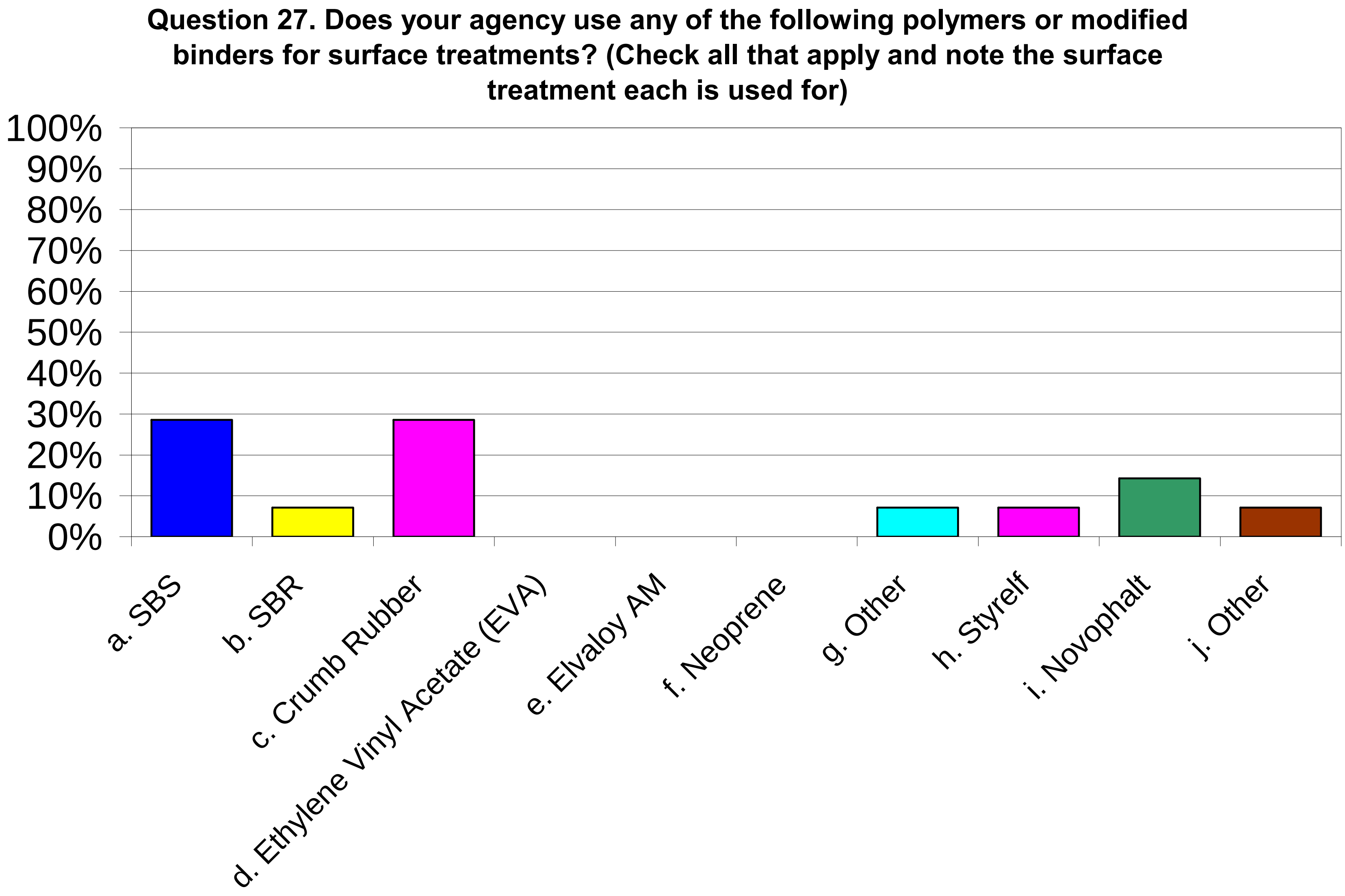
Respondent #	Response
1	No.
2	-
3	-
4	Yes. If needed case by case.
5	Minnesota chip seal design program
6	-
7	We use the ISSA tests for Micro surfacing. We use the sales representative's design for Nova chip.
8	Contractor designed
9	Yes, require mix designs and compatibility tests for emulsion and aggregates
10	No
11	We test all aggregates for quality and soundness. Emulsions are tested
12	
13	Minimal. We use a SY test (trial and error) for rejuvs, slurries and micros we follow national concepts (ISSA designs). Novachip is left up to the supplier.
14	-

Question 26. Does your agency use any of the following polymers or modified binders for thin lift HMA overlays? (Check all that apply and note the thin lift overlay each is used for)



<u>Question 26:</u> Does your agency use any of the following polymers or modified binders for thin lift HMA overlays? (Check all that apply and note the thin lift overlay each is used for)

Respondent #	Response
1	c. PPEST
2	-
3	-
4	-
5	-
6	-
7	-
8	a. Dense graded & 6.3 mm HMA b. Dense graded & 6.3 mm HMA d. Dense graded & 6.3 mm HMA e. Dense graded & 6.3 mm HMA g. Dense graded & 6.3 mm HMA
9	-
10	-0
11	a. PG 64-28, 1" of RLC b. PG 64-28, 1" of RLC
12	
13	
14	-

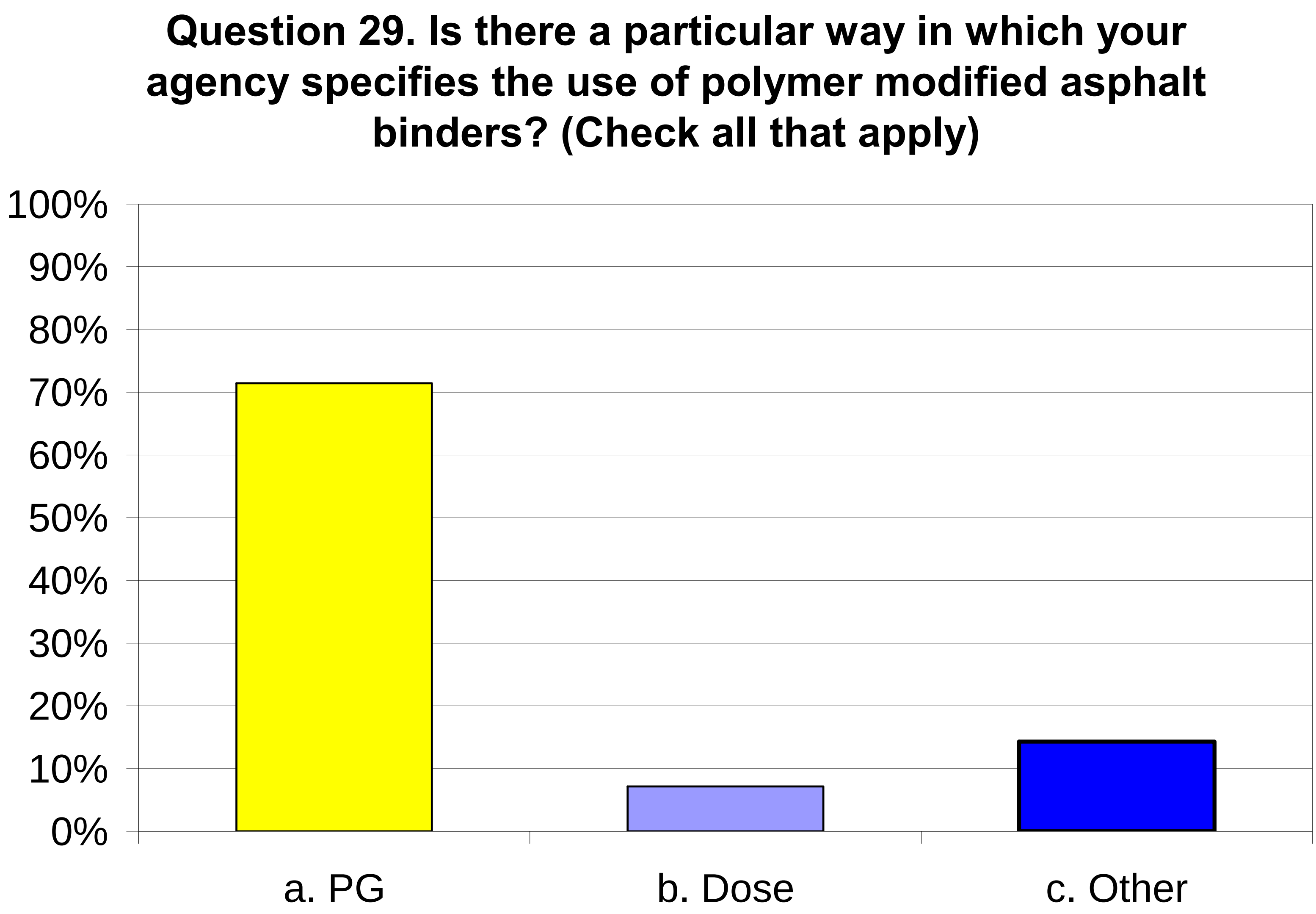

Question 27. Does your agency use any of the following polymers or modified binders for surface treatments? (Check all that apply and note the surface treatment each is used for)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
a. SBS
b. SBR
c. Crumb Rubber
d. Ethylene Vinyl Acetate (EVA)
e. Elvaloy AM
f. Neoprene
g. Other
h. Styrelf
i. Novophalt
j. Other

<u>Question 27:</u> Does your agency use any of the following polymers or modified binders for thin lift HMA overlays? (Check all that apply and note the thin lift overlay each is used for)

Respondent #	Response
1	c. RACS
2	-
3	-
4	-
5	-
6	-
7	-
8	g. all the above are allowed, but not tracked j. all the above are allowed, but not tracked
9	-
10	i. Scrub Seals
11	-
12	-
13	-
14	-

<u>Question 28:</u> If your agency is currently using polymer modified asphalt, what is the base PG and what is the target PG (Example: begin with PG 64-28, end with PG 76-34) or does your agency use PG+ Grading Specifications? (Please list)

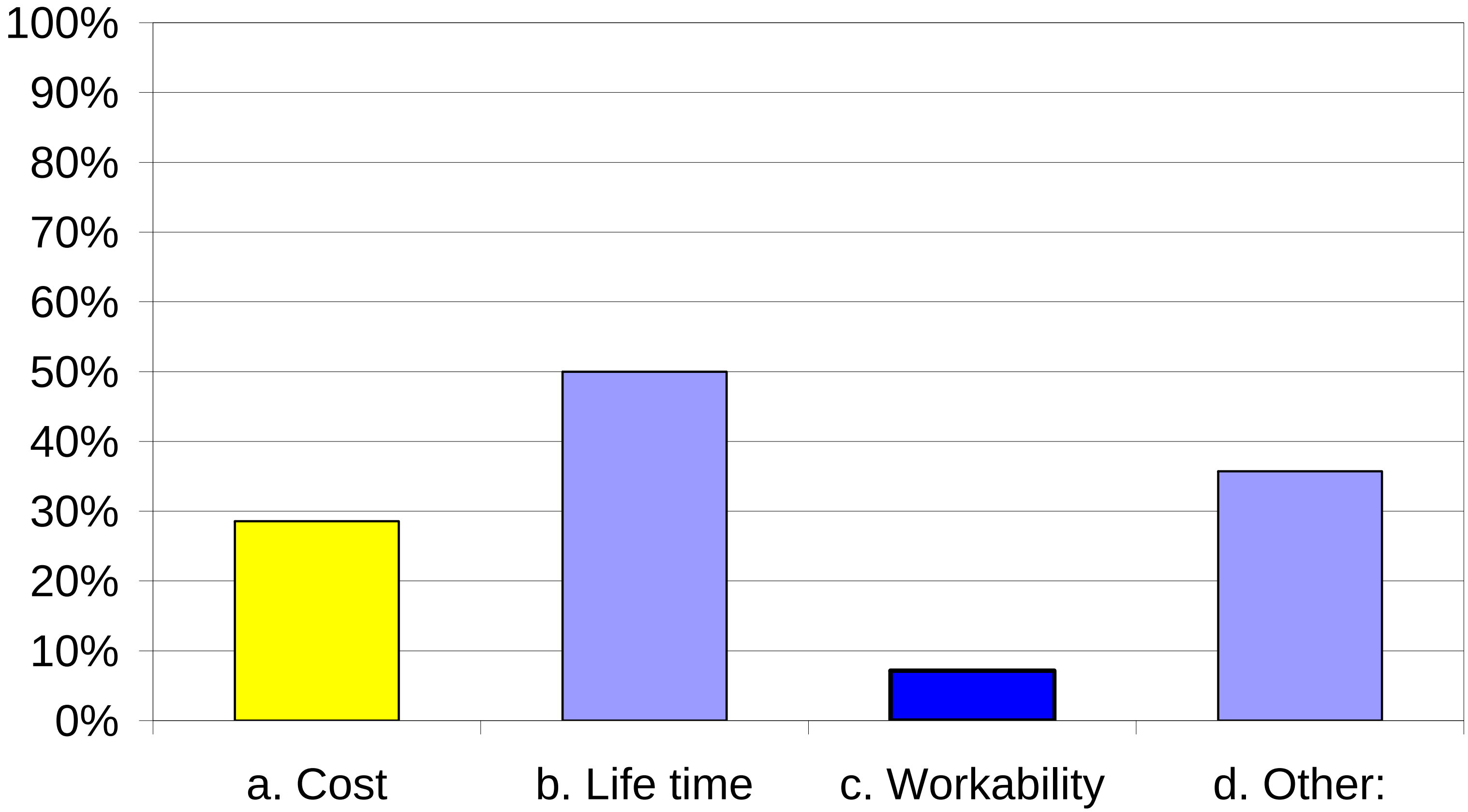
Respondent #	Response
1	PPEST: Base: PG 58-XX Target: PG 76-34
2	-
3	For HMA, the asphalt suppliers start with a PG 52-34 to achieve a PGXX-28. NOTE: you cannot lower the low end temperature grade with polymer modification.
4	asphalt binder PG 64-16
5	52-34 -base 58-34 modified also use 58-28 unmodified
6	Base Grade - 67-22, target PG - 76-22 or lower grade Base Grade - 67-22, target PG - 82-22 or lower grade
7	We specify the target PG binder we use PG+ specs for our PG 64-28 binder
8	We use PG+ with elastic recovery
9	PG+ with elastic recovery spec
10	64-28NV Northern Nevada 76-22NV Southern Nevada
11	We use PG+ specs
12	-
13	We use PG+ Specs, allowing the supplier to determine how to meet our end result requirements. The plus part comes in the requirements for an enhanced G*, phase angle, elastic recovery and Direct Tension stress and strain values.
14	PG 58-34 PM, PG 64-28PM, PG 76-22PM www.dot.ca.gov/hg/esc/oe/specifications for more details


Question 29. Is there a particular way in which your agency specifies the use of polymer modified asphalt binders? (Check all that apply)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
a. PG
b. Dose
c. Other

Question 29: **Is there a particular way in which your agency specifies the use of polymer modified asphalt binders? (Check all that apply)**

Respondent #	Response
1	Both PG grade (PG 76-34) and dose (minimum 7% crumb rubber).
2	-
3	-
4	-
5	-
6	-
7	-
8	Elastic Recovery
9	-
10	-
11	-
12	-
13	-
14	-

Question 30. If your agency is using polymer modified asphalts what are the factors for deciding one over the other? (Check all that apply)



<u>Question 30:</u> If your agency is using polymer modified asphalts what are the factors for deciding one over the other? (Check all that apply)

Respondent #	Response
1	-
2	-
3	Proper material selection for the desired pavement performance
4	Region, climate
5	-
6	-
7	We use PG binders based on Superpave recommendations throughout the state.
8	Do not indicate preference
9	-
10	-
11	-
12	-
13	Life-Cycle based on performance and cost
14	-

<u>Question 31:</u> Have you or your agency noticed any advantages or disadvantages of using polymer modified asphalt? (Please list and explain)

Respondent #	Response
1	Performance of PPEST as a thin overlay.
2	The asphalt rubber chip seals have had exceptional performance to date.
3	modified binders are specified when needed
4	Extend pavement life, reduce cracking.
5	yes reduced cracking
6	-
7	We are currently evaluating this question.
8	currently under evaluation
9	advantages include less cracking and rutting
10	No
11	We allow polymer modified binders in all of HMA mixes.
12	-
13	We have virtually eliminated rutting in our state and reduced our thermal cracking by 70% to 80%.
14	-