# Survey on the Use of Rubber Modified Asphalt Pavements in Cold Regions

Note: Photo courtesy of MTO

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| **PROJECT SUMMARY PAGE** | **Date:** Feb 28, 2012 |
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| **Title: Survey on the Use of Rubber Modified Asphalt Pavements in Cold Regions** | |
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**Abstract:**

This report presents the results of an international survey on the use of rubberized asphalt products in cold regions. Agencies surveyed included those in North America, China, and Scandinavia. A total of 40 responses to the survey were returned indicating widespread use of rubber in asphalt pavements.

Based on the survey responses, there is wide interest in using ground tire rubber in asphalt pavements. The following are the major conclusions from the survey:

1. There were 16 agencies which reported they utilize asphalt rubber binder, 13 use terminal blend binder, and a few agencies use asphalt rubber chip seals or as interlayers. This means that rubber products have been utilized in many parts of the world. The benefits and barriers of the use of these products were identified

2. Asphalt rubber can be used effectively in gap- and open-graded mixes. Asphalt binder contents in gap- and open-graded mixes are normally higher than for dense-graded mixes. Terminal blends can be used in dense- or open-graded mixes. The binder contents used by various agencies are summarized in the report.

3. The mix design procedures for using rubberized products vary from agency to agency. The most commonly used are Marshall, Superpave, and Hveem in descending order.

4. The pavement design methods include AASHTO, Mechanistic Empirical (ME) methods, and local empirical designs. The AASHTO method is the most widely used. Some agencies allow reduced thickness based on their experience; however, most do not. In lieu of reducing thickness, they expect improved performance compared with conventional mixes.

5. High binder content Asphalt Rubber (AR) chip seals and interlayers are more durable and effective for resisting reflective cracking. Expected life of an asphalt rubber chip seal varies based on locations. The range of life is from 5 to 15 years.

6. Rubberized asphalt pavements have been recycled. However, more studies are needed if Recycled Asphalt Pavement (RAP) content is high.

7. Warm mix technology can be a big help to reduce the limitations of using rubber product in pavements.



**Keywords:**

Ground Tire Rubber, Asphalt Rubber, Rubberized Asphalt Concrete, Chip seals and Interlayers

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# Disclaimer

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The content does not necessarily reflect the official views or policies of the Ontario Tire Stewardship (OTS) or the Ministry of Transportation of Ontario (MTO).

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# 1.0 INTRODUCTION

## 1.1 Background

Stockpiles of waste tires, especially illegally dumped, have caused significant damage to the public health, safety, and environment. Tire piles are not only aesthetically disagreeable, but if mismanaged pose a fire hazard. Tire fires are characterized by incomplete combustion resulting in thick clouds of toxic black smoke and the liberation of toxic oils. Since the Hagersville tire fire on February 12, 1990, a number of Canadian provinces have re-examined their approach to used-tire management, and have initiated programs to promote tire recycling and the development of markets for recycled tire products (Murray, 1996).

The Ministry of Transportation of Ontario (MTO) is considering a program to use recycled tires in asphalt pavements. The potential benefit of this application is great because the use of tire rubber in asphalt mixes can increase the engineering properties and this application could consume a lot of waste tires. To determine the potential benefits, the OTS and MTO would like to determine the performance of rubberized asphalt products used in cold regions for the following applications:

- Hot mix asphalt with and without a Stress Absorbing Membrane Interlayer (SAMI layer);
- Rubberized asphalt with warm mix additives; and
- Rubberized asphalt chip seals or surface treatments.

This task will consist of a survey of users throughout the world on the use of rubberized asphalt in a variety of applications. The focus is to identify the performance of rubberized asphalt products in cold regions similar to those found in Ontario, Canada.

## 1.2 Project Objectives

The purpose of the survey project is to identify the extent of use of rubberized asphalt, the performance of rubberized asphalt used especially in cold regions, and to develop a summary report based on the survey. The survey report will further help with the effective application of crumb tire rubber in Ontario and aid with the development of related specifications.

## 1.3 Project Scope

This report includes the following chapters:

- Chapter 2 describes the survey questions for targeted audiences;
- Chapter 3 summarizes the responses from the surveys; and

- Chapter 4 contains the conclusions of the survey along with recommendations for rubber modified asphalt pavement.

# 2.0 SURVEY DEVELOPMENT

This task consists of a survey of users throughout the world on the use of rubberized asphalt in a variety of applications. The focus is to identify the performance of rubberized asphalt products in cold regions similar to those found in Ontario. The survey was emailed to various users in the fall of 2011 in the following regions of the world:

- United States;
- Canada (Alberta, British Columbia, Yukon, and Ontario);
- Scandinavia (Sweden, Denmark, and Finland); and
- China.

## 2.1 Survey Form

The questions were sent out to the various countries and agencies. The survey consisted of a website based survey in which the agencies could answer the questions easily and quickly. Topics consisted of general questions, questions on mixes, questions on chip seals (including interlayers), and more. The survey was mailed out in October 2011 and the final responses were received in November 2011. The complete questionnaire is given in Appendix A.

## 2.2 Terminology Used in the Survey

It was deemed necessary to make clear the terminology for rubberized asphalt products. Hence, the following descriptions were provided with the survey to inform survey participants to use consistent terminology.

**Asphalt Rubber:** According to the ASTM definition (ASTM D 8), asphalt rubber is a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 % by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles. Recycled tire rubber is referred to as crumb rubber modifier (CRM). The asphalt cement and CRM are mixed and interacted at elevated temperatures and under high agitation to promote the physical interaction of the asphalt cement and CRM constituents.

**Terminal Blend:** This is a form of the wet process where finer CRM is blended with hot asphalt cement at the refinery or at an asphalt storage and distribution terminal and transported to the Hot Mix Asphalt (HMA) mixing plant or job site for use. This type of rubberized asphalt does not require subsequent agitation to keep the CRM particles evenly dispersed in the modified binder. The CRM particles used in the terminal blend are finer than the No. 30 sieve size (0.6 mm) so they can be digested relatively quickly and can be kept dispersed by normal circulation within the storage tank rather than by special augers or paddles.

**Asphalt Rubber Chip Seals:** This is a chip seal in which asphalt rubber is applied, followed by a layer of chips, and rolling. The binder application rates are much higher than those used for conventional chip seals. These binders are sprayed hot and require hot chips precoated with asphalt.

**Asphalt Rubber Interlayers:** This is a spray application of asphalt rubber binder and chips similar to a chip seal. The spray application is overlaid with an asphalt paving mix that may or may not include CRM.

**CRM:** It is a general term for scrap tire rubber that is reduced in size for use as a modifier in asphalt paving materials. It includes several types including ground crumb rubber modifier, high natural rubber, buffing wastes, etc. CRM can be produced using ambient grinding, cryogenic grinding, granulation, or shredding. The equipment used for producing the CRM can be cracker mill, granulator, or a micro-mill.

# 3.0 SURVEY RESPONSES

A total of 40 responses to this survey were received as of December 1, 2011. The following sections show the agencies which responded to the survey and the summary of survey results. Appendix B identifies the agencies which responded to the survey

## 3.1 Agencies and Countries Responding to the Survey

The following table shows the countries and agencies which responded to the survey. They provided important knowledge and information on the current usage of rubberized asphalt in asphalt pavements.

Table 3.1. Agencies and countries that provided survey responses

| No | Company | City | State/Province | Country |
|---|---|---|---|---|
| 1 | City of Calgary | Calgary | Alberta | Canada |
| 2 | Alberta Transportation | Edmonton | Alberta | Canada |
| 3 | New Brunswick DOT | Fredericton | New Brunswick | Canada |
| 4 | Nova Scotia Transportation Infrastructure Renewal | Fall River | Nova Scotia | Canada |
| 5 | Ministry of Transportation of Ontario | Toronto | Ontario | Canada |
| 6 | Saskatchewan Ministry of Highways and Infrastructure | Saskatoon | SK | Canada |
| 7 | Yukon Government | Whitehorse | Yukon | Canada |
| 8 | Jiangsu Transportation Research Institute | Nanjing | Jiangsu | China |
| 9 | Chang'an university | Xi'an | Shanxi | China |
| 10 | Danish Road Institute | Hedehusene | | Denmark |
| 11 | Sito Oy | Tampere | | Finland |
| 12 | Svevia | Falun | Dalecarlia | Sweden |
| 13 | Alabama DOT | Montgomery | Alabama | USA |
| 18 | Alaska DOT &PF | Anchorage | Alaska | USA |
| 15 | Arkansas HTD | Little Rock | Arkansas | USA |
| 23 | Arizona DOT | Phoenix | Arizona | USA |
| 16 | California Pavement Preservation Center | Chico | California | USA |
| 19 | Delaware DOT | Dover | Delaware | USA |
| 24 | Florida DOT | Gainesville | Florida | USA |
| 25 | Georgia DOT | Forest Park | Georgia | USA |
| 20 | Iowa DOT | Ames | Iowa | USA |
| 26 | Idaho Transportation Department | Boise | Idaho | USA |
| 14 | Kansas DOT | Topeka | Kansas | USA |
| 27 | Kentucky Transportation Cabinet | Frankfort | Kentucky | USA |
| 28 | Minnesota DOT | Maplewood | Minnesota | USA |
| 29 | Missouri DOT | Jefferson City | Missouri | USA |
| 30 | Montana DOT | Helena | Montana | USA |
| 31 | North Carolina DOT | Raleigh | North Carolina | USA |
| 32 | Nevada DOT | Carson City | Nevada | USA |
| 33 | New Jersey DOT | Trenton | New Jersey | USA |
| 21 | Ohio DOT | Columbus | Ohio | USA |
| 34 | Oklahoma DOT | Oklahoma City | Oklahoma | USA |
| 35 | Pennsylvania DOT | Harrisburg | Pennsylvania | USA |
| 36 | Rhode Island DOT | Providence | Rhode Island | USA |
| 37 | South Carolina DOT | Columbia | South Carolina | USA |
| 22 | South Dakota DOT | Pierre | South Dakota | USA |
| 17 | Tennessee DOT | Nashville | Tennessee | USA |

| | | | | |
|---|---|---|---|---|
| 38 | Utah DOT | Salt Lake City | Utah | USA |
| 39 | Washington DOT | Olympia | Washington | USA |
| 40 | Wyoming DOT | Cheyenne | Wyoming | USA |

## 3.2 Summary Reponses for Using Rubber in Pavements

The results from all the responses to the questions in the survey are summarized in this section of the report.

### *3.2.1 Responses to General Questions*

**Question: Do you use asphalt rubber for any of the following applications: HMA, Chip Seal, or Interlayer?**

The survey results (total of 40 responses) showed that there are many agencies that use rubberized asphalt in asphalt concrete mixes. Not many agencies use the rubberized asphalt chip seals or asphalt rubber interlayers. Figure 3.1 shows the survey results for this question. Rubberized asphalt has been used worldwide. A total of 20 agencies replied that they use rubber in hot mix. Eight said that they use rubber in chip seals, and six said that they use rubber in interlayers. It has been used in the cold regions of the United States, Sweden, Finland, Denmark, Canada, and China.

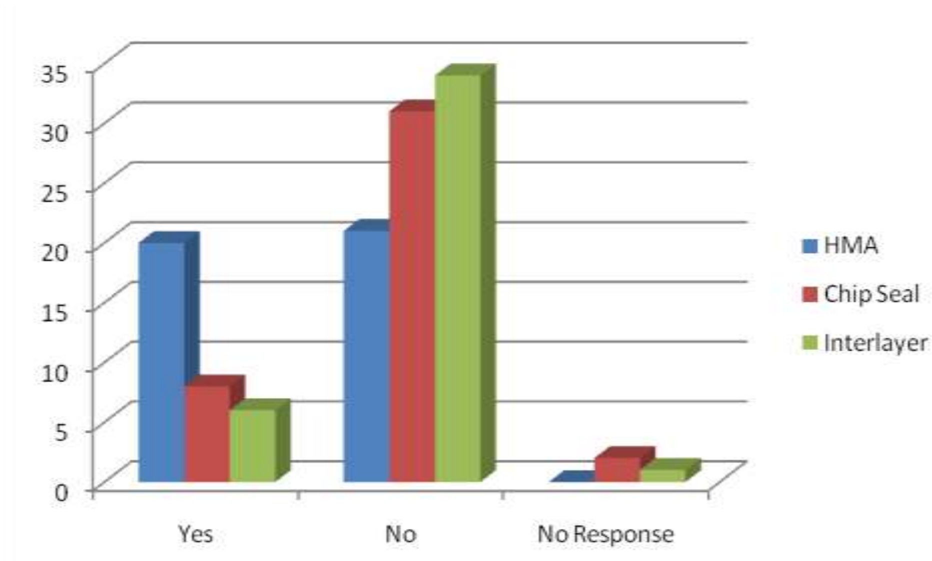


**Figure 3.1. Status of agencies using tire rubber in asphalt pavements**

**Question: What sort of binders do you use?**

Out of the 40 survey responses, sixteen indicated they utilized asphalt rubber binders, thirteen used terminal blend rubberized binders, and two indicated they used other types of rubberized binders. Out of the other types, one indicated using dry process in their mix, which means that CRM was used as part of the aggregate; another indicated that their crumb rubber modifier is about 10% of the binder content. Figure 3.2 shows the binder type usage. The ***asphalt rubber*** is used in more places than ***terminal blends***.

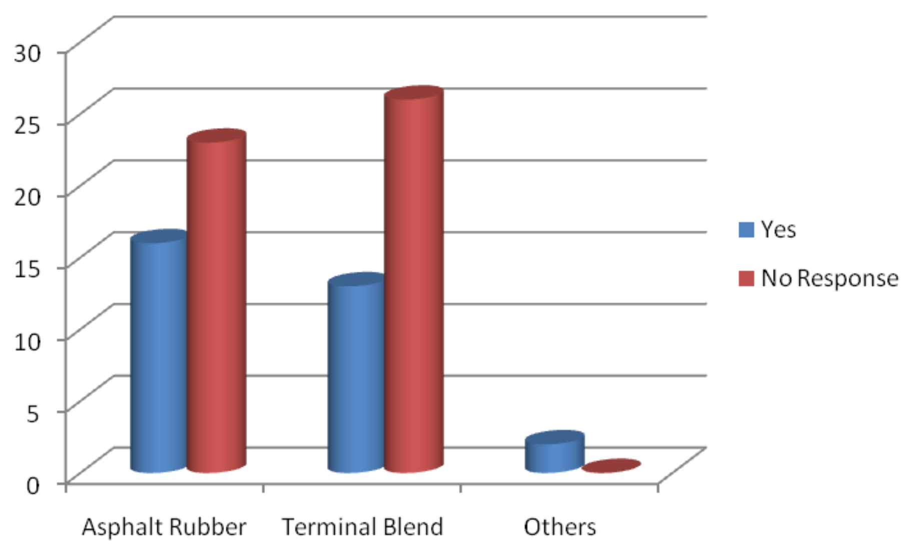


**Figure 3.2. Status of agencies using different types of rubberized binders**

**Question: How often do you use asphalt rubber products?**

There were eight agencies which said that they routinely use asphalt rubber or terminal blends in their pavements, which means that they know how to effectively utilize the rubberized asphalt in their pavements. Eleven agencies said they rarely use it and six indicated other. The answers for the other category include (1) only one test section, (2) research only, (3) experimental AR chip seal, (4) past trial projects, (5) used on experimental bases, (6) 3 test cases, and (7) when needed.

Figure 3.3 shows the results of how often responding agencies utilize asphalt rubber or terminal blends in their regions. Apparently, there is a need for knowledge transfer when using these products because only 8 out of 40 agencies utilize rubber modified asphalt routinely.

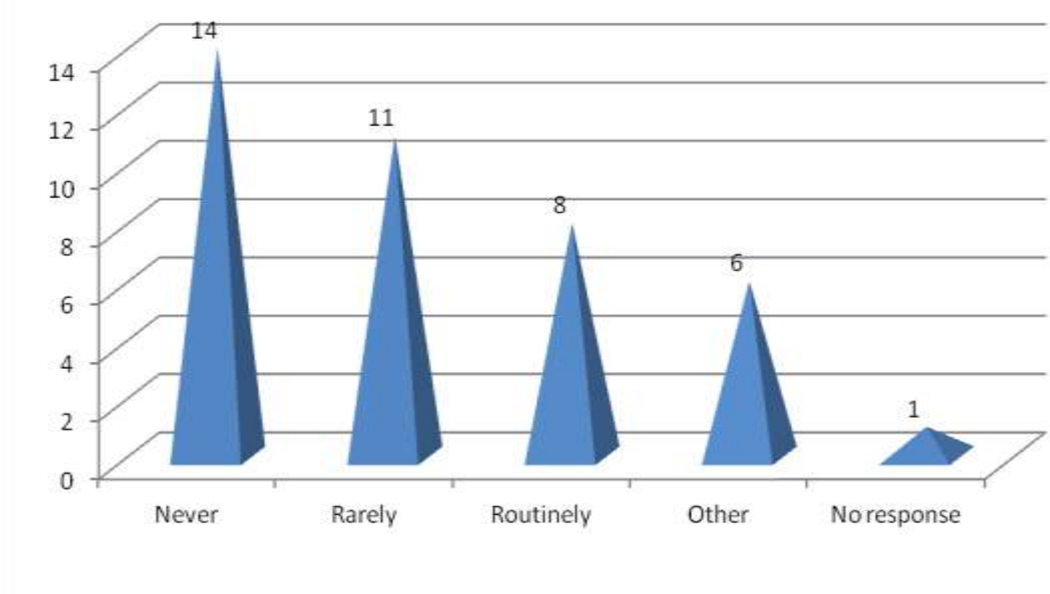


**Figure 3.3. Survey results on how often the agencies use rubberized asphalt pavement**

**Question: What are the benefits and limitations of using rubberized asphalt products? Do you have any documentation of each?**

There have been mixed results in terms of using tire rubber products in pavement. Tables 3.2 and 3.3 list the benefits and limitations based on agencies' past experiences, respectively.

**Table 3.2. Benefits of using crumb rubber modifier in pavements**

| Agencies | Benefits of using rubber modified binder |
|---|---|
| Alaska DOT & PF | Resists studded tire wear.<br>Adds additional friction for winter driving. |
| Arizona DOT | Increases durability.<br>Increases resistance to oxidative aging.<br>Increases resistance to reflective cracking.<br>Quiet and smooth.<br>Recycling of tires which would otherwise end up in landfills. |
| City of Calgary, Alberta | Reduces reflective cracking.<br>Improves resistance to rutting.<br>Decreases traffic noise levels (Initial, but not maintained after 1 year service).<br>Allows reduction in paving thickness. |
| Danish Road institute, Denmark | Tire recycling, cracking resistance is better on some projects. Can use effectively in areas with cobble pits. Less thickness required (60 % of conventional AC thickness is designed using asphalt rubber. |

| | |
|---|---|
| Delaware DOT | Competition for polymer modified rubbers to keep costs lower. |
| Florida DOT | Improves cracking resistance for dense graded mixes.<br>Reduces raveling of open graded friction courses.<br>Some improvement in rutting resistance by stiffening the binder.<br>Research conducted by the University of Florida documents some of the benefits. |
| Georgia DOT | Can provide reduced project costs while maintaining quality and at the same time provides a productive outlet for end-of-life tires. |
| Jiangsu Transportation Research Institute, China | Good durability and sliding stability.<br>Decreases noise pollution.<br>Uses a waste resource. |
| Nevada DOT | Viscosity is very high, adhesion property is very good |
| New Jersey DOT | Use asphalt rubber in Open Graded Friction Courses. We have seen benefits with the longevity of the OGFC along with the wet weather accident and noise reduction seen with the use of OGFC. |
| Ohio DOT | Good elasticity and flexibility. |
| Oklahoma DOT | Better performance than virgin binder. |
| Ontario Ministry of Transportation | Resistance to reflection cracking. |
| Pennsylvania DOT | 2007 AR experimental seal coat project appeared to provide good performance with minimal stone loss.<br>AR or terminal blend in HMA is best suited for Gap-Graded or OGFC mixtures.<br>Penn DOT does not use OGFC's due to past use which resulted in aggregate anti-skid material clogging up the openings resulting in water retention and freezing causing more winter icing conditions and resulting in higher rock salt application rates.<br>Our use of Gap-Graded HMA mixtures is mainly for SMA mixtures, but lack of AR blenders or terminal blend limits its application in Gap-Graded SMA. However, we have incorporated CRM in SMA in a dry process as a mastic stabilizing agent on two SMA projects since 2009 which have performed well to date. |
| Rhode Island DOT | Better performance. |

| | |
|---|---|
| Saskatchewan Ministry of Highways and Infrastructure | Use of asphalt rubber would replace the addition of polymers in mixes, therefore resulting in potential cost savings. |
| Sito Oy, Finland | It's more flexible than ordinary asphalts and it is used to avoid reflective cracking between concrete and asphalt pavements. |
| South Carolina DOT | Recently started to use some terminally blended PG 76-22 on some trial projects as an alternate modifier to SBS modified PG 76-22. We have done some limited SAMI projects over old deteriorating concrete pavements. |
| Svevia, Sweden | Mitigates reflection cracking.<br>Improves adhesion of bitumen to aggregates.<br>Increases softening point of binder.<br>Increases fatigue life. |

**Table 3.3. Limitations of using crumb rubber modifier in pavements**

| **Agencies** | **Limitations on using rubber modified binder** |
|---|---|
| Alabama Department of Transportation | Current market prices for CRM are higher than SBS in Alabama.<br>Another limitation is keeping the liquid asphalt tank agitated when asphalt rubber is used. |
| Alaska DOT/PF | Cost is high so use only on high volume roads that rut quickly.<br>Note that the "Dry Process" is used. |
| Arizona DOT | Limited paving window due to temperature constraints.<br>Some mixes can be more difficult to compact and require more effort on the part of the contractor.<br>Construction inspectors must have high degree of training and experience in order to be assured all specifications are met. |
| Chang'an University, Shanxi Province | High temperature for producing asphalt rubber.<br>More energy should be used for producing asphalt rubber.<br>More greenhouse gas will be produced.<br>High temperature performance of CRM is not better than SBS modified asphalt mixture. |
| City of Calgary, Alberta | Higher production costs.<br>Does not appear to maintain long-term noise reduction qualities.<br>Does not appear to stop all reflective cracking. |
| Delaware DOT | Costs<br>Unknown long-term performance. |
| Georgia DOT | Crumb rubber modified asphalt (rubber at 10% of liquid AC) is allowed in Superpave mix, as an alternate to polymer modified asphalt, at Contractor's discretion.<br>It is not allowed for SMA and OGFC. |
| Ministry of Highways and Infrastructure | Compaction can be difficult; some area may not have suitable aggregates.<br>Only 2 contractors in province.<br>Limitations on available period in year due to weather restrictions. |

| | |
|---|---|
| Nebraska DOT | Cost<br>Consistency<br>Availability |
| Nevada DOT | Issues with moisture sensitivity have been encountered in the past. |
| Nova Scotia TIR | Department tried one pilot project, but we were un-successful and the project was cancelled. |
| Ohio DOT | Cost based on trials in 2009. |
| Oklahoma DOT | More expensive<br>Fewer sources |
| Ontario Ministry of Transportation | Inexperience of hot mix industry with rubberized asphalt concrete.<br>Shortage of quality CRM meeting specifications. |
| Pennsylvania DOT | Limited AR blending companies for onsite or project specific blending of AR and limited terminal blend companies to provide terminal blend. Mobilization of AR blenders results in higher costs which limits their use due to current tight funding situation.<br>We have tried AR and CRM (dry process) in several dense-graded HMA projects in the past several decades as experimental projects with mixed results. Some performed fairly well or equal to the dense-graded HMA control section, but some did not have equal performance with the HMA control section.<br>Higher CRM percentages in these dense-graded HMA projects resulted in poorer performance too. |
| Rhode Island IDOT | Binder performance grading is more challenging. |
| Utah DOT | Difficult to pave in cold weather. |
| Washington DOT | Increased cost for the same or reduced performance. |

**Question: When did you start using these rubber products by application: HMA, chip seal, and interlayer?**

Asphalt rubber was invented by Charles H. McDonald of the City of Phoenix, Arizona in the 1960s. At that time, it was mainly used in hot mix patching and surface treatments. In 1975, Caltrans began experimenting with asphalt rubber chip seals and small test patches in Yolo County and Sacramento County. In 1978, Caltrans constructed its first rubberized asphalt concrete pavement on SR 50 near Meyers Flat. Table 3.4 shows responses from different agencies that illustrate when they started to use rubber in asphalt rubber chip seals. Table 3.5 shows the starting year of agency usage of rubberized asphalt mixes, and Table 3.6 shows the starting year of agency usage of interlayers. With the increasing importance of recycling and sustainable green practice, more agencies and countries will try to use recycled tire in their pavement applications.

Terminal blends came along later around the 1990s. The states of Texas and Florida used them initially, but now they are used in many other states including Arizona, California, Nevada, Oregon and in the northeast part of the United States.

**Table 3.4. Starting year of using rubber in chip seal applications**

| Agency | Mix starting year |
|---|---|
| Alberta DOT | 2003 |
| Arizona DOT | 1998 |
| California DOT | 1975 |
| Delaware DOT | 2005 |
| Kansas DOT | 2002 |
| Nevada DOT | 2010 |
| Oklahoma DOT | 2004 |
| Pennsylvania DOT | 2007 |
| Rhode Island DOT | 1999 |
| Washington DOT | 1977 |

**Table 3.5. Starting year of using rubber in the asphalt mixes**

| Agency | Mix starting year |
|---|---|
| Alabama DOT | 2010 |
| Alaska DOT/PF | 1986 |
| Alberta DOT | 2002 |
| Arizona DOT | 1988 |
| California DOT | 1978 |
| Chang’an, China | 2008 |
| City of Calgary, Alberta Canada | 2002 |
| Delaware DOT | 2000 |
| Denmark | 2009 |
| Finland | 1990 |
| Florida DOT | 1994 |
| Georgia DOT | 2007 |
| Jiangsu Transportation Research Institute, China | 2006 |
| Nevada DOT | 2008 |
| New Jersey DOT | 1991 |
| Ohio DOT | 1993 |
| Ontario Ministry of Transportation | 1980 |
| Pennsylvania DOT | 2004 |
| Rhode Island DOT | 2001 |
| Saskatchewan Ministry of H & I | 2005 |
| South Carolina DOT | 2011 |
| Svevia, Sweden | 2007 |
| Washinton State DOT | 1982 |

**Table 3.6. Starting year of using rubber in interlayer applications**

| Agency | Mix starting year |
|---|---|
| Arizona DOT | 1977 |
| Florida DOT | 1994 |
| Jiangsu Transportation Research Institute, China | 2005 |
| Rhode Island DOT | 2000 |
| Washington DOT | 1977 |

### *3.2.2 Responses to Mix Related Questions*

**Question: For the hot mix asphalt applications, do you use the asphalt rubber in the following mix types: dense-, gap-, and open-graded?**

Rubberized asphalt has been used in different types of mixes including dense-, gap- , and open-graded. Due to high viscosity and relatively large rubber particle size used in the asphalt rubber wet process, California and Arizona use asphalt rubber mostly in gap- and open-graded designs. Because of the finer rubber used in terminal blends, these modified asphalts have been used in dense- and open-graded mixes in Arizona, California, and Florida. Figure 3.4 shows the number of agencies using different types of asphalt rubber mix designs. Tables 3.7 through 3.9 show the agencies using dense-, gap-, and open-graded mixes, respectively. Rubber has been used in other types of mixes as well. Sweden and Denmark have used tire rubber in stone matrix asphalt (SMA) mix. This is referred to as stone mastic asphalt in Ontario.

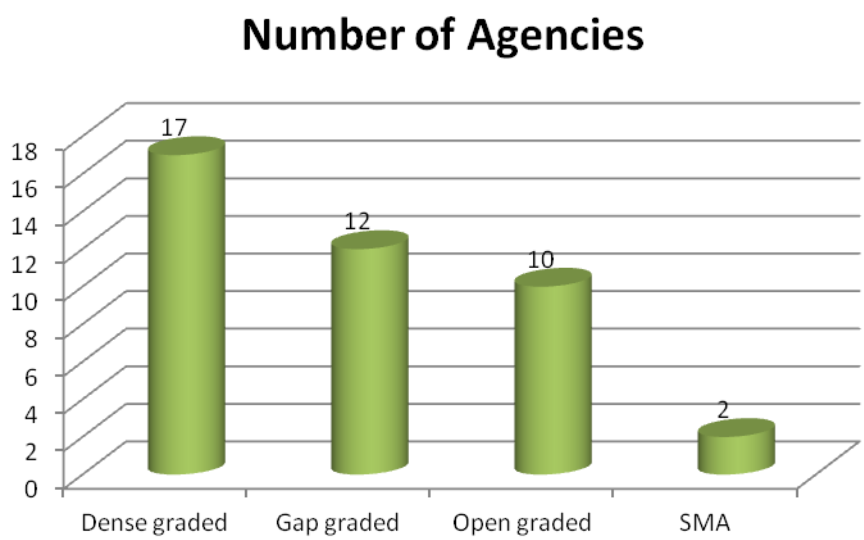


**Figure 3.4. Number of agencies using different types of rubberized asphalt pavement**

**Table 3.7. Agencies using rubber in dense-graded mixes**

| Agency | Dense graded mix |
|---|---|
| Alabama DOT | Yes |
| Arizona DOT | Yes |
| California DOT | Yes |
| Chang'an, China | Yes |
| City of Calgary, Alberta | Yes |
| Danish Road Institute, Denmark | Yes |
| Delaware DOT | Yes |
| Florida DOT | Yes |
| Georgia DOT | Yes |
| Nevada DOT | Yes |
| Ohio DOT | Yes |
| Ontario Ministry of Transportation | Yes |
| Pennsylvania DOT | Yes |
| Saskatchewan Ministry of H & I | Yes |
| Sito Oy, Finland | Yes |
| South Carolina DOT | Yes |

**Table 3.8. Agencies using tire rubber in gap-graded mixes**

| Agency | Gap graded mix |
|---|---|
| Alaska DOT & PF | Yes |
| Alberta DOT | Yes |
| Arizona DOT | Yes |
| California DOT | Yes |
| Chang'an University | Yes |
| City of Calgary, Alberta | Yes |
| Jiangsu Transportation Research Institute, China | Yes |
| Ontario Ministry of Transportation | Yes |
| Pennsylvania DOT | Yes |
| Rhode Island DOT | Yes |
| Saskatchewan Ministry of H & I | Yes |
| Svevia, Sweden | Yes |

**Table 3.9. Agencies using tire rubber in open-graded mixes**

| Agency | Open graded mix |
|---|---|
| Alberta DOT | Yes |
| Arizona DOT | Yes |
| California DOT | Yes |
| Chang'an University | Yes |
| Florida DOT | Yes |
| Jiangsu Transportation Research Institute, China | Yes |
| Nevada DOT | Yes |
| New Jersey DOT | Yes |
| South Carolina DOT | Yes |
| Svevia, Sweden | Yes |

**Question: What are typical binder contents for each mix type (percentage by weight of total mix)?**

Binder content is a very important parameter related to the durability and performance of rubberized asphalt pavement. Table 3.10 shows the responses from various agencies on their typical binder contents for different types of rubber modified asphalt pavements including dense-, gap-, and open-graded, as well as SMA mixtures.

Typically, the range in binder contents for dense-graded is from 5 to 6.5% by weight of total mix. The gap- and open-graded rubberized asphalt have higher binder contents than dense-graded mixes. The typical values for gap-graded and open- graded are between 7-9%. The 3% binder content used by Tennessee DOT is for base material, not the surface layer.

**Table 3.10. Typical binder contents for different pavement types in different agencies**

| Agency | Dense Graded (%) | Gap Graded (%) | Open Graded (%) | SMA (%) |
|---|---|---|---|---|
| Alabama DOT | 6.0 | | | |
| Alaska DOT/PF | | 6.5 | | |
| Arizona DOT | 4.5 TR+ | 8.0 AR | 9.0 AR and 6.5 TR+ | |
| California DOT | 6.5 | 7.5 | 8.0 | |
| Chang'an university | 8.0 | 7.0 | 7.5 | |
| Danish Road institute, Denmark | 4.8 | | | 6.0 and 6.4 |
| Delaware DOT | 5.8 | | | |
| Florida DOT | 5.5 | | 6.5 | |
| Georgia DOT | 5.0 | | | |
| Jiangsu Transportation Research Institute, China | | 7.6 | 7.6 | |
| Nevada DOT | 4.5 to 6.5 | | 5.5 to 7.5 | |
| New Jersey DOT | | | 7.5 to 8.5 | |

| | | | | |
|---|---|---|---|---|
| Ohio DOT | 5.9 | | | |
| Ontario Ministry of Transportation | 5.8 | 7.5 | | |
| Pennsylvania DOT | 5.0 to 5.8 | 6.0 to 7.4 | | |
| Rhode Island DOT | | 7.0 min | | |
| Saskatchewan Ministry H & I | 6.8 to 8.5 | 6.8 to 8.5 | | |
| South Carolina DOT | 5.0 | | 6.5 | |
| Svevia, Sweden | | 8.5 - 9.5 | 8.5 - 9.5 | 8.5 - 9.5 |
| Tennessee DOT | 5.8 | 3 | 6.0 | |

Note: The 3% binder content for gap-graded used by Tennessee DOT is for base material, not the surface layer.

**Question: Do you have specifications for each of the mix types you use? If yes, please email us a copy or provide a link to the specifications.**

So far, we have received specifications from all the agencies shown in Table 3.11. More specifications are being collected through literature and agency contacts. A separate report summarizing the specs is under development.

**Table 3.11. Agencies which provided specifications for rubberized asphalt mixes**

| No. | Agency |
|---|---|
| 1 | Arizona DOT |
| 2 | California DOT |
| 3 | Florida DOT |
| 4 | Georgia DOT |
| 5 | Jiangsu, China |
| 6 | Massachusetts DOT |
| 7 | New Jersey DOT |
| 8 | Ontario Ministry of Transportation |
| 9 | Rhode Island DOT |
| 10 | Tennessee DOT |
| 11 | Texas DOT |

**Question: Do you have specifications for rubber modified binders? If yes, please email us a copy or provide a link to the specifications.**

So far, we have received specifications from the agencies shown in Table 3.12. More specifications will be collected through literature and agency contacts.

Table 3.12. Agencies which provided specifications for rubberized asphalt

| No. | Agency |
|---|---|
| 1 | Arizona DOT |
| 2 | California DOT |
| 3 | Florida DOT |
| 4 | Georgia DOT |
| 5 | Jiangsu, China |
| 6 | Massachusetts DOT |
| 7 | New Jersey DOT |
| 8 | Oklahoma DOT |
| 9 | Texas DOT |

**Question: What mix design procedure do you use for rubber mixes and can you send us a copy of the procedure and the criteria used?**

Figure 3.5 shows the number of surveyed agencies using different mix design procedures. Marshall mix design is the most widely used method by the agencies surveyed. Superpave mix design is being looked at but not fully developed. Ontario MTO is using the Superpave mix design approach. Table 3.13 illustrates the mix design procedure that agencies are currently using.

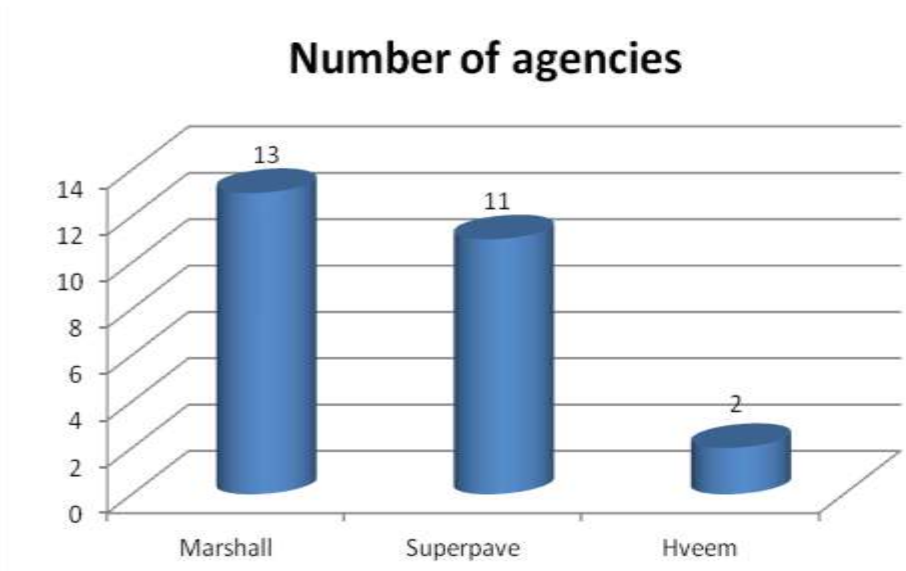


Figure 3.5. Number of agencies using different mix design techniques

**Table 3.13. Mix design procedure used or being evaluated by various agencies**

| Agency | Marshall | Superpave | Others |
|---|---|---|---|
| Alabama DOT | | Superpave | |
| Alaska DOT & PF | Marshall | | |
| Alberta Department of Transportation | Marshall | | |
| Arizona DOT | Marshall | | |
| California DOT | | | Hveem |
| Chang'an University | Marshall | Superpave | |
| City of Calgary, Alberta | Marshall | Superpave | |
| Danish Road institute, Denmark | Marshall | | |
| Delaware DOT | | Superpave | |
| Florida DOT | | Superpave | |
| Georgia DOT | | Superpave | |
| Jiangsu Transportation Research Institute, China | Marshall | | |
| Nevada DOT | | | Hveem |
| New Jersey DOT | | | New Jersey method |
| Ohio DOT | Marshall | Superpave | |
| Ontario Ministry of Transportation | | Superpave | |
| Pennsylvania DOT | | Superpave | |
| Rhode Island DOT | Marshall | Superpave | |
| Saskatchewan Ministry of H & I | Marshall | | |
| South Carolina DOT | | Superpave | |
| Svevia, Sweden | Marshall | | Dynamic creep |
| Tennessee DOT | Marshall | | |

**Question: What sort of problems, if any, have you had with asphalt rubber hot mixes? Please indicate by yes or no for each of the problems encountered.**

Figure 3.6 shows pavement distresses experienced from the rubberized asphalt pavement placed by each agency. Overall, most of the agencies reported no distresses in their pavements. Typical distresses reported include coarse aggregate loss, cracking, stripping or raveling, bleeding, and rutting in descending order.

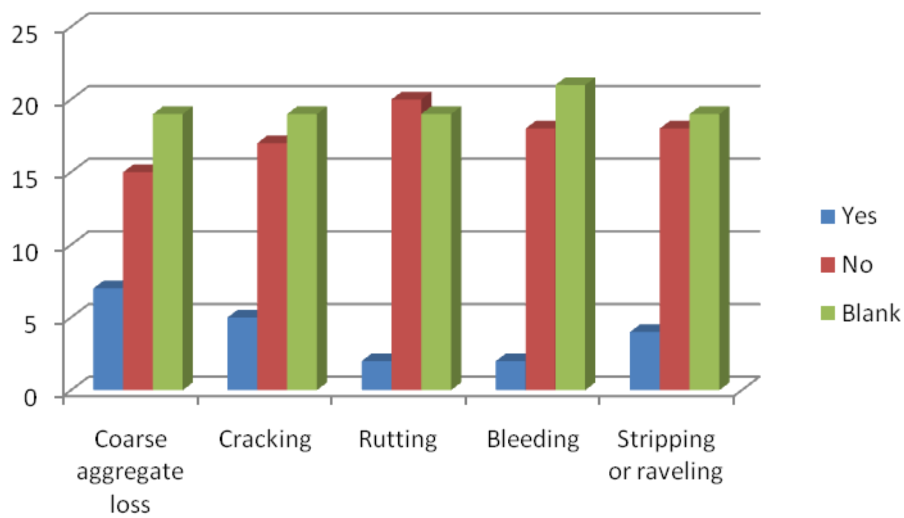


**Figure 3.6. Common pavement distress types encountered for rubberized asphalt pavements**

**Question: What sort of pavement design procedure do you use to design the thickness of the asphalt rubber mixes?**

Figure 3.7 provides a summary of the responses on pavement design procedures used by various agencies when designing rubber modified asphalt pavement. As can be seen, most of the agencies use the AASHTO method at this time.

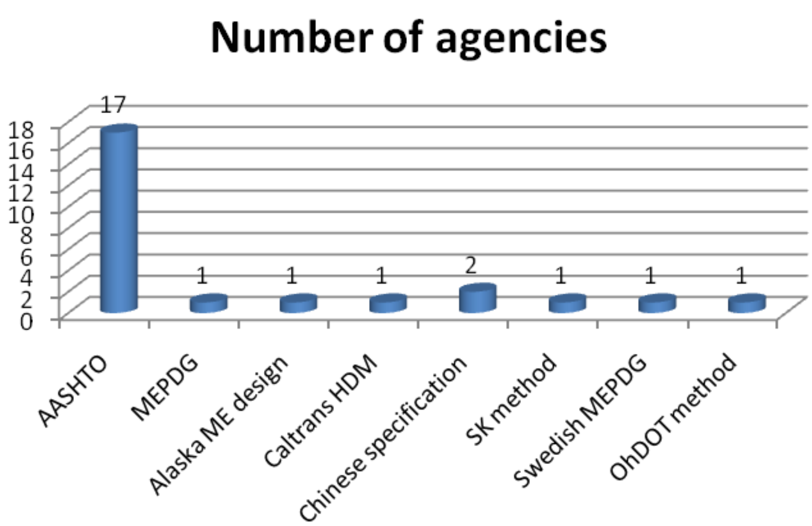


**Figure 3.7. Pavement design procedures used by agencies**

**Question: Do you allow for a reduced layer thickness when using asphalt rubber hot mixes?**

A total of 26 agencies responded to this question, of which 5 agencies including California (Caltrans 2006) allow reduced thickness. Figure 3.8 shows the percent of agencies which allow reduced thickness when using rubberized asphalt as an overlay. As can be seen, most agencies do not allow reduced thickness for rubberized asphalt pavement design. However, experiences from different agencies have shown benefits such as longer life and less maintenance of rubber modified pavement when they are applied effectively.

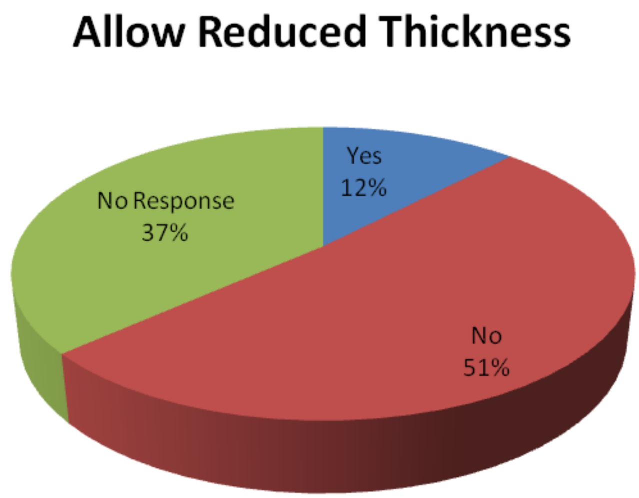


**Figure 3.8. Agencies that allow reduced thickness.**

### *3.2.3 Responses to Chip Seal or Interlayer Questions*

**Question: Do you use asphalt rubber chip seals or interlayers?**

Although AR chip seals have been used since the 1960s, the major cold region users of this treatment are concentrated in the United States and China as shown in Table 3.14. Figure 3.9 illustrates the number of agencies utilizing the asphalt rubber chip seal or interlayer.

Table 3.14. Agencies using AR Chip Seal or Interlayer

| Use AR Chip Seal or Interlayer |
|---|
| Arizona DOT |
| California DOT |
| Chang'an University |
| Delaware DOT |
| Florida DOT |
| Jiangsu Transportation Research Institute, China |
| Kansas DOT |
| Nevada DOT |
| Oklahoma DOT |
| Pennsylvania DOT |
| Rhode Island DOT |

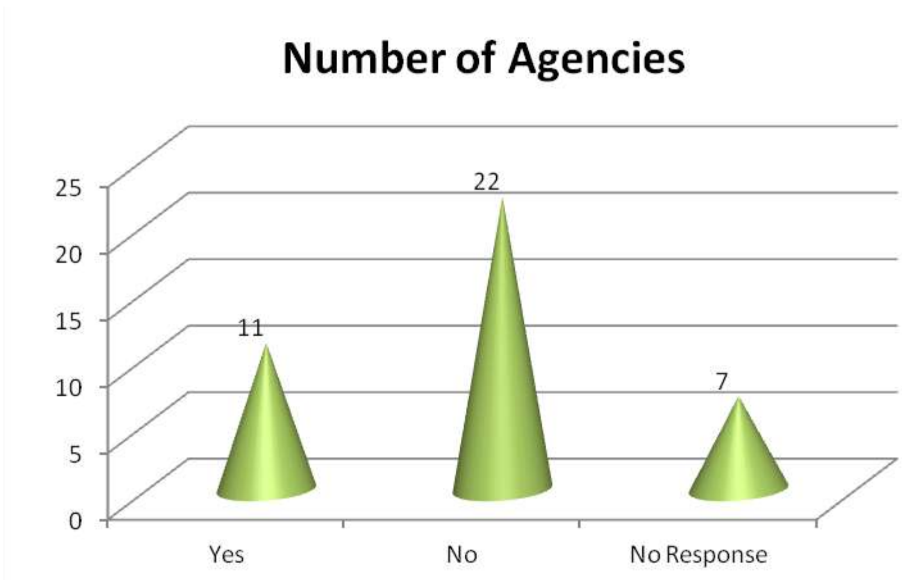


Figure 3.9. Number of agencies using asphalt rubber chip seal or interlayer

**Question: What are typical binder application rates for chip seals ($gal/yd^2$ or $l/m^2$) or interlayers ($gal/yd^2$ or $l/m^2$)?**

Table 3.15 shows the typical application rates of asphalt rubber binder used in AR chip seals or interlayers. The application rate of AR chip seals is similar to that of interlayers. The higher application rate will make the treatment more resistant to cracking and may last longer. However, over spraying of binder could cause bleeding.

Table 3.15. Binder application rate for asphalt rubber chip seals and interlayers

| Agencies | Rubberized Chip Seals | Rubberized Interlayers |
|---|---|---|
| Arizona DOT | 0.55 +/- .05 gal/yd$^2$ | 0.60 gal/yd$^2$ max |
| California DOT | 0.65 gal/yd$^2$ | 0.65 gal/yd$^2$ |
| Delaware DOT | 0.30 gal/yd$^2$ | |
| Florida DOT | | 0.60gal/yd$^2$ |
| Jiangsu Transportation Research Institute, China | | 1.3 kg/m$^2$~1.6kg/m$^2$ |
| Kansas DOT | 0.40 gal/yd$^2$ | |
| Nevada DOT | 0.25 gal/ yd$^2$ | |
| Oklahoma DOT | 0.3 gal/ yd$^2$ | |
| Rhode Island DOT | 0.60 gal/ yd$^2$ | 0.60 gal/yd$^2$ |
| South Carolina DOT | 0.30-0.35 gal/ yd$^2$ - CRS-2P | |
| Tennessee DOT | 0.30 gal/ yd$^2$ | 0.30 gal/ yd$^2$ |

**Questions: 16.What sorts of problems, if any, have you had with asphalt rubber chip seals or interlayers?**

Figure 3.10 illustrates the distresses that some agencies experienced for some of their projects. Most agencies answered that they did not experience any problems.

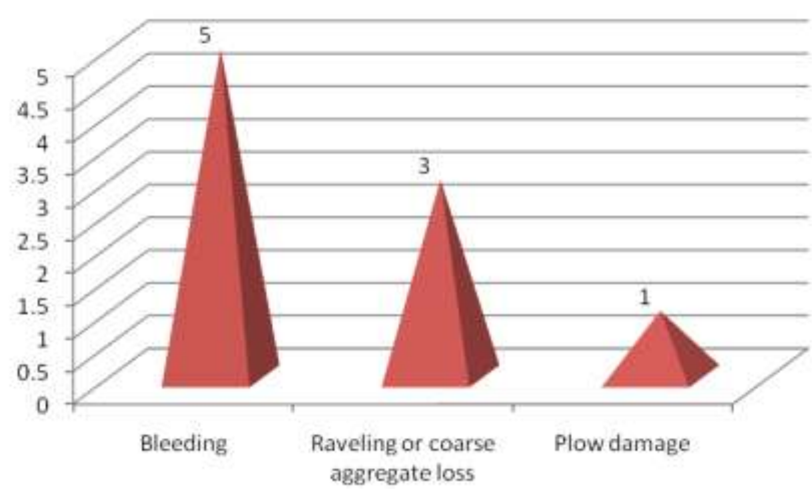


Figure 3.10. Common distresses for asphalt rubber chip seals or interlayers

**Question: What is the expected life of chip seals or interlayers in years?**

A few agencies provided expected lives for their asphalt rubber chip seal projects. However, the actual treatment life depends on many factors including existing pavement structure and condition, traffic, and environmental situations. Most of the longer lives for AR chip seals or interlayers come with higher binder contents.

**Table 3.16. Expected life of chip seals or interlayers**

| Agencies | Expected life, years |
|---|---|
| Arizona DOT | 5 to 10 |
| California DOT | 5 to 10 |
| Delaware DOT | 5 |
| Florida DOT | 15 |
| Jiangsu Transportation Research Institute, China | 10 |
| Kansas DOT | 5 |
| Nevada DOT | 5 |
| Oklahoma DOT | 10 |
| Pennsylvania DOT | 5 |
| Rhode Island DOT | 10 |
| South Carolina DOT | 5 to 7 |
| Tennessee DOT | 5 |

### *3.2.4 Responses to Other Questions*

**Question: Have you recycled asphalt rubber products? If yes, please provide a summary of your experience.**

Table 3.17 summarizes the responses on recycling asphalt rubber products. Some agencies have successfully recycled rubberized asphalt pavement or seal coats. Currently, the performance and emissions of the recycled rubber products are not any worse than recycling other types of pavement as long as the percentage of RAP from rubber products is kept low, such as less than 15 %.

**Table 3.17. Agencies' experiences with recycling asphalt rubber products**

| | |
|---|---|
| Alaska DOT & PF | Not enough tires to economically justify equipment to recycle tires for HMA. |
| Arizona DOT | Gap graded ARAC is milled and used as RAP. |
| California DOT | Caltrans allows using rubberized asphalt pavement as RAP for up to 15% into new hot mix asphalt.<br>Caltrans conducted a study in 2005, which showed that rubberized asphalt concrete could be recycled by hot plant recycling, full depth reclamation, and CIR. Since rubberized asphalt concrete can be recycled into dense graded asphalt concrete, there is no need to mix existing rubber into new rubberized asphalt concrete because it will not increase rubber usage (Caltrans 2005). |
| Florida DOT | We use lower percentages of rubber in our mixes (5% in dense-graded mixes; 12% in open-graded mixes) so it hasn't been a problem, so far. |
| Kentucky DOT | One job in 1993. |
| New Jersey DOT | Recycled a Plus Ride pavement back in the 1990s - a TRB report was published at the time. -- Look for a report by Eileen Connolly and Robert Baker.<br>Basically, there were no problems recycling 10% in a surface course. |
| Ontario Ministry of Transportation | Just once in 1991 on Hwy 2 in Thamesville, Ontario. We managed to re-use rubberized RAP in the new HMA. However emissions were slightly elevated compared to the regular HMA. |

**Question: Have you used warm mix additives with asphalt rubber products? If yes, please identify the warm mix technologies that you used.**

Warm mix technology can reduce the mixing and construction temperatures of rubber modified asphalt pavement, which can significantly reduce the emissions. Warm mix technologies can also lower the viscosity of asphalt rubber binder, which can extend the construction season, increase opportunities for cool temperature paving, and overcome long haul distances. As shown in Figure 3.11, eight agencies replied that they have tried the warm mix technology with rubberized asphalt pavements. The warm mix technologies that were used by these agencies are shown in Table 3.18.

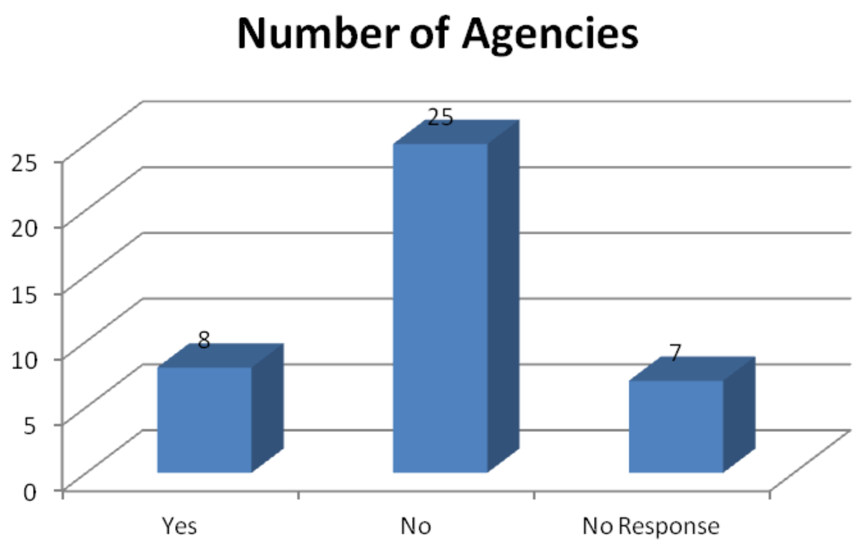


**Figure 3.11. Number of agencies that used asphalt rubber warm mix in their pavements**

**Table 3.18. Warm mix technologies used by agencies on rubber products**

| **Agencies** | **Warm Mix Technologies** |
|---|---|
| Alaska DOT/PF | Evotherm additive,<br>Contractor did not place mix as required so data is unavailable. |
| California DOT | Advera, Evotherm, Sasobit are allowed.<br>Aztec Double Barrel Green, Engineering additives, and several others are still in testing stage.<br>No problems with the use. |
| Chang'an University, China | Sasobit and Evotherm warm mix additives have been used. |
| Danish Road institute, Denmark | The way we have tried crumb rubber in Denmark recently is through the Road+ concept (Crumb rubber + Vestanamer). |
| Florida DOT | Several - mainly Aztec Double Barrel Green foaming process. |
| New Jersey DOT | Have used a PG 64-22 modified with Evotherm to blend the rubber into.<br>We were able to then keep the temperature below 300° F and significantly reduced fumes. |
| Rhode Island DOT | Sasobit, Sonnewarmix |
| Svevia, Sweden | Cement and Wetfix |

**Question: Are there any other comments you wish to add regarding the topics covered in this survey?**

There were additional comments from those who responded to the survey about using rubber in asphalt pavements. The detailed comments are shown in Table 3.19. Overall, people would like to see successful research and clear definitions about the rubberized asphalt concrete and seal coat applications.

**Table 3.19. Other comments about rubberized asphalt pavement survey**

| **Agencies** | **Other Comments from Agencies** |
|---|---|
| Alabama DOT | Alabama has only used asphalt rubber on one test section. Test section mix was produced using a terminal blend asphalt rubber. |
| City of Calgary, Alberta | Interested in noise attenuation studies. |
| Florida DOT | Florida has found that SBS polymers typically outperform asphalt rubber in terms of both rutting and cracking.<br>We also get less handling complaints from contractors when we use SBS modified binders and our mix costs are lower with SBS as well. |
| Idaho DOT | Idaho Transportation Department has not used asphalt rubber, but we are interested in learning more. |
| Missouri DOT | Missouri does not use asphalt rubber; however, chemically cross linked asphalt with crumb rubber is used in HMA.<br>This performs very well to date. |
| North Carolina DOT | We are currently evaluating the use of Ground Tire Rubber |
| Oklahoma DOT | AC15-5TR and AC20-TR used in Chip Seals section |
| Rhode Island DOT | The definitions between Asphalt Rubber and Terminal Blend are still confusing to some. From the definition it appears that a terminal blend could be an asphalt rubber, but an asphalt rubber cannot be a terminal blend. Is that correct? What happens if you want an asphalt rubber at a mesh size of less than 30? |
| Sito Oy, Finland | Our experience covers only designing. |
| South Carolina DOT | Not at this time, we are in the early stages of terminally blended GTR binders.<br>We only have one project that is currently underway.<br>We have a specification that was written exclusively for use of that particular project, and have not adopted the GTR completely at this point. |
| Washington DOT | Not enough use within WSDOT to quantify. See attached links for WSDOT use.<br>http://www.wsdot.wa.gov/research/reports/fullreports/693.1.pdf<br>http://www.wsdot.wa.gov/research/reports/fullreports/683.1.pdf<br>http://www.wsdot.wa.gov/research/reports/fullreports/691.1.pdf<br>http://www.wsdot.wa.gov/research/reports/fullreports/749.1.pdf |

## 3.3 Phone Interviews with Canadian Agencies

The objectives of interviewing some Canadian Agencies are to obtain some past experiences, to obtain lessons learned, and to support Ontario's asphalt rubber application effort.

### *3.3.1 Alberta Infrastructure and Transportation*

Simon Hesp of Queen's University did a phone interview with Chuck McMillan who is in charge at Alberta Transportation with respect to their asphalt activities. The experience in Alberta was not a very positive one. Cold weather regions face unique challenges that can make the introduction of new technologies difficult. A few large failures can stop the use of AR for a long time. The following are the notes from the phone interview:

**Summary of discussion with Chuck McMillan, Alberta DOT (October 19, 2011)**

1) A write-up on Alberta's recent experience with AR is provided in the CTAA 2007 proceedings (Juhasz and McMillan, 2007).

2) In 2002 three jurisdictions paved small AR trials (Calgary, Edmonton and Strathcona County). A company from Arizona was retained to do the blending of crumb rubber with the asphalt cement. Mix designs were done in Arizona by experienced companies.

3) Full projects were constructed in 2003, 2004, 2005 and 2006. HMA tonnage for some of the larger contracts reached 8,300 and 12,300. A local company acquired the blending unit to prepare the AR for each contract.

4) Some full scale contracts were placed on high volume highways including the TransCanada Yellowhead Highway 16.

5) Several paving contractors were involved and they all hired the one local blender.

6) Failures occurred early, for some within the first year. Failures appeared to be stripping related and this may have been due to the lack of filler (lime, hydrated lime, etc.), which was later learned to be included in the Arizona formulations as an anti-strip agent since AR mixes are supposedly more prone to stripping.

7) Crumb rubber used was <2 mm; although this might not have been a well graded source with perhaps too much of the material around 2 mm.

8) Mixes were gap-graded and Marshall designs.

9) Asphalt cement contents were in the range of 7-9 %, with some as low as 6 %.

10) One source from Alberta was used to produce the crumb rubber.

11) There were no good performing contracts and some of the high volume roads had to be replaced after just a few years. There may still be one contract on a low volume road but it will not last the 20 years that is typical for regular Alberta pavements with unmodified asphalt cement. Hence, life cycle cost benefits were not realized.

12) Asphalt cement came from Husky, Imperial and Moose Jaw asphalt. Grades were 150/200 and 200/300 pen. These are close to what is normally used or somewhat softer.

13) There are no indications that any extender/softening oils were used. However, the possibility exists that this could have been a confounding factor.

14) The likely reason for the stripping/generalized raveling failures on these contracts was the large crumb rubber size combined with the fact that the "fillers" were left out of the recipe. Alberta normally does not use antistrip and left out the hydrated lime because they have naturally fine gradations.

15) High in place voids (low compaction) must also have been a contributing factor.

16) Advice for Ontario is to do this very carefully since a few early failures can kill all prospects for the widespread use of AR.

### 3.3.2 Cities of Edmonton and Calgary

Simon Hesp spoke to both Hugh Donovan (Edmonton) and Joe Chyc-Cies (Calgary) and met them both at a meeting. Their impressions from their use of AR were very similar to those of Chuck McMillan of Alberta Transportation. Hence, Ontario has to do a better job for this to become a success, assuring the long term use of recycled rubber in asphalt pavements. Simon suggested to do some AR interlayers with superior quality surface layers containing only premium quality asphalt cement. His opinion is that regular AR in surface courses can also work but not if they regularly have waste engine oil residues in the base asphalt cement sabotaging the medium and long term performance. The following are the summaries of the discussions.

**Summary of Discussions with Hugh Donovan of the City of Edmonton**

Hugh Donovan of the City of Edmonton is in charge of their asphalt program. He shared his experiences with AR that started 9 years ago.

1) They constructed some 19 trials from 2002-2006. Typical volumes ranged from a low of 1,000 tonnes to a high of 5,000 tonnes.

2) Traffic levels varied but most projects were on arterial roads with heavy bus and truck traffic.

3) Two contractors were involved, one for blending the AR and the other for constructing the pavement sections.

4) The first few Marshall mix designs were done in Arizona (MACTEC) while the last few were done in Edmonton by local contractors.

5) All mixes were gap-graded and the asphalt cement content was a little higher than regular mixes (6.8%). Mixes stripped from the start since hydrated lime was left out. Major raveling problems occurred and today all but one have been replaced thus creating significant extra cost.

6) The main reasons for early failures are high voids and stripping problems. Large crumb rubber size was also likely a contributing factor in failures.

**Summary of Discussions with Joe Chyc-Cies of the City of Calgary**

Joe Chyc-Cies is in charge of the City of Calgary's asphalt program. He shared his experiences with AR that started 9 years ago.

1) They constructed 7 trials starting in 2002 and the volumes ranged from a low of 2,000 tonnes to a high of 7,500 tonnes.

2) There were three different contractors involved and consultants were hired to do Marshall mix design. They used a Marshall design with 50 blows which would have resulted in slightly richer mixes than what was used by others in Alberta. Typical AC contents ranged from 7.5 to 7.8%. The in-place voids (compaction) achieved were all within limits and below 8%.

3) All mixtures were gap-graded and the crumb rubber size ranged from minus 10 (2 mm) to minus 30 (0.6 mm) mesh. All mixes were designed following Arizona guidelines. No additional oils were added to his knowledge. Base asphalt cement would have been Husky 150/200 penetration grades.

4) Alberta Recycle provided the CRM free of charge. FATH did all the AR blending for the seven trials.

5) All trials were considered successful although the most recent indication is that they perform about as good as regular hot mix asphalt. The main benefit of the AR was a reduction in traffic noise but that benefit was significantly reduced after the first year or two.

# 4.0 CONCLUSION AND RECOMMENDATIONS

Based on the results from the survey of cold regions in the world, the following conclusions and recommendations from this study appear warranted.

## 4.1 Conclusions

Based on the 40 responses from different countries, mostly from parts of the United States and Canada, there is wide interest in using rubber in asphalt pavements. The following are the major conclusions from the survey:

1. There are 15 agencies utilizing asphalt rubber binder, 13 using terminal blend rubber, and some agencies using asphalt rubber chip seals or as interlayers. This means that rubber product has been utilized in many parts of the world.

2. Based on the responses from agencies, the following are the benefits of using rubber modified binders:

a. Improved performance;
b. Competition with more expensive polymer modified binders;
c. Improved elasticity;
d. Improved durability and reduced aging;
e. Quiet and smooth pavements;
f. Improved crack resistance;
g. Increased fatigue life;
h. Possible reduction in paving thickness;
i. Reduced wet weather accident rates with open-graded mixes; and
j. Energy and environmental savings associated with recycling and reuse of waste tires.

3. There are barriers with using rubber products in asphalt pavement, such as the following:

    a. Inexperience of hot mix industry;
    b. Shortage of quality CRM;
    c. Binder performance grading of asphalt rubber;
    d. Compaction issues;
    e. Weather restrictions;
    f. Cost, equipment, availability;
    g. High temperatures for production and construction;
    h. Limited paving window; and
    i. Need for an established Superpave mix design procedure.

4. Asphalt rubber can be used effectively in gap- and open-graded mixes. Asphalt binder contents in gap- and open-graded are normally higher than for dense-graded mixes. Terminal blends can be used in dense- or open-graded mixes. The binder contents used by various agencies are summarized in the report.

5. The mix design procedures for using rubberized products vary. The most commonly used are Marshall, Superpave, and Hveem in descending order.

6. The pavement design methods include AASHTO, Mechanistic Empirical methods, and local empirical designs. The AASHTO method is the most widely used

7. Some agencies allow reduced thickness based on their experiences; however, most do not. They expect improved performance compared with conventional mixes.

8. High binder content AR chip seal and interlayer are more durable and effective for resisting reflective cracking.

9. Expected life of asphalt rubber chip seal varies based on locations. The range is wide from 5 to 15 years.

10. Rubberized asphalt pavement can be recycled. However, more studies are needed if RAP content is high.

11. Warm mix technology can be a big helper to reduce the limitations of using rubber product in pavements. Some agencies including Caltrans have successfully utilized several warm mix technologies.

## 4.2 Recommendations

The following recommendations are made based on rubber asphalt online survey results:

1. There are many different specifications on rubberized asphalt products. A more detailed study on specifications should be conducted. A summary report on the specifications used by various regions should help develop a more suitable specification for Ontario.

2. Research documentation was provided by some of the surveyed agencies. It would be helpful to synthesize the research results over the past to provide better guidance for agencies that are interested in increasing rubber usage.

# 5.0 REFERENCES


1. Caltrans, Asphalt Rubber Usage Guide, California Department of Transportation, September, 2006.
2. Caltrans, Feasibility of Recycling Rubber Modified Paving Materials, State of California Department of Transportation, February 2005.
3. Marta Juhasz and Chuck McMillan, Alberta Infrastructure and Transportation's Experience with Asphalt Rubber, Alberta Infrastructure and Transportation, Edmonton, Alberta, Canada, 2007.
4. William Murray, Tire Recycling, BP 431-E. Canada, 1996.

# 6.0 APPENDIX

## Appendix A: Online Survey Questionnaire

The following are the links to the online asphalt rubber survey:

http://www.cp2info.org/cp2c/survey/OTSarSurvey/OTSarSurvey.php

## General questions

1. Do you use asphalt rubber for any of the following applications? (yes or no)
    - Hot mix asphalt
    - Chip seals
    - Interlayers

2. What sort of binders do you use?
    - Asphalt rubber
    - Terminal blend
    - Other (please specify)

3. How often do you use asphalt rubber products
    - Never
    - Rarely
    - Routinely
    - Other (please specify)

4. What are the benefits and limitations of using rubber products? Do you have any documentation of each? If you do, please send us a copy.
    - Benefits
    - Limitations

5. When did you start using these products by application? (year)
    - Hot mix asphalt
    - Chip seals
    - Interlayers
    - Other

If you have any reports on long term performance evaluations of pavements containing rubber, could you please send us a copy?

## Mixes

6. For the hot mix asphalt applications, do you use the asphalt rubber in the following mix types? (yes or no)
   - Dense-graded
   - Gap-graded
   - Open-graded
   - Other

7. What are typical binder contents for each mix type? (percentage by weight of total mix)
   - Dense-graded
   - Gap-Graded
   - Open-graded
   - Other (please specify)

8. Do you have specifications for each of the mix types you use? (yes or no). If yes, please email us a copy or a link to the specifications.

9. Do you have specifications for rubber modified binders? (yes or no) If yes, please email us a copy or a link to the specifications.

10. What mix design procedure do you use for rubber mixes and can you send us a copy of the procedure and the criteria used?
    - Marshall
    - Superpave
    - Other (please specify)

11. What sort of problems if any have you had with asphalt rubber hot mixes? Please indicate by a yes or no for each of the problems encountered.

    - Early coarse aggregate loss or raveling
    - Cracking-load associated or non-load associated
    - Rutting
    - Bleeding (flushing)
    - Others (please specify)

12. What thickness design procedure do you use for pavements with asphalt rubber mix?

- AASHTO
- MEPDG
- Other (please specify)

13. Do you allow for a reduced layer thickness when using asphalt rubber hot mixes? (yes or no)

## Chips seals or interlayers

14. Do you use asphalt rubber chip seals or interlayers? (yes or no)

15. What are typical binder application rates for the chip seals (g/yd$^2$ or l/m$^2$) or interlayers (g/yd$^2$ or l/m$^2$)?

16. What sort of problems if any have you had with asphalt rubber chip seals or interlayers? Please indicate by a yes or no for each of the problems encountered.
    - Bleeding
    - Raveling or coarse aggregate loss
    - Others (please specify)

17. What has been the long term (8 years) performance of chip seals or interlayers
    - Good
    - Moderate
    - Poor

## Other questions

18. Have you recycled asphalt rubber products? If yes, please provide a summary of your experience.

19. Have you used warm mix additives with asphalt rubber products? If yes, please identify the warm mix technologies that you used.

20. Would you like more information on the use of asphalt rubber products?

21. Are there any other comments you wish to add?

22. Can you suggest any other contact in your area who could contribute to this effort? Contact name, email and phone:____________________

## Appendix B: Online Survey Participants

The following table shows the survey participants in alphabetic order of their last names.

| First name | Last name | Company | City | State | Country |
|---|---|---|---|---|---|
| Newton | Bingham | Alaska DOT/PF | Anchorage | Alaska | USA |
| Ralph | Campbell | NB Dept. of TransportationNew Brunswick DOT | Fredericton | New Brunswick | Canada |
| DingXin | Cheng | California | Chico | California | USA |
| Joe | Chyc-Cies | The City of Calgary | Calgary | Alberta | Canada |
| Janet | Doerstling | Arizona DOT | Phoenix | AZ | USA |
| Bryan | Engstrom | Rhode IslandRIDOT | Providence | RI | USA |
| Rick | Harvey | Wyoming DOT | Cheyenne | Wyoming | USA |
| Kenneth | Hobson | Oklahoma DOT | Oklahoma City | Oklahoma | USA |
| Ken | Jeffrey | Yukon Government | Whitehorse | Yukon | Canada |
| Manoj | Jogi | Ministry of Highways and Infrastructure | Saskatoon | SK | Canada |
| Carl | Lenngren | Svevia, Sweden (state owned construction company), | Falun | Dalecarlia | Sweden |
| Gary | Loyd | Alabama Department of TransportationDOT | Montgomery | Alabama | USA |
| Chuck | McMillan | Alberta Transportation | Edmonton | Alberta | Canada |
| Tamara | Murry | AHTD | Little Rock | Arkansas | USA |
| Jim | Musselman | Florida DOT | Gainesville | Florida | USA |
| Allen | Myers | Kentucky DOTTransportation Department | Frankfort | KY | USA |
| Erik | Nielsen | Danish Road Institute | Hedehusene | | Denmark |
| Jim | Pappas | Delaware DOT | Dover | DE | USA |

| | | | | | |
|---|---|---|---|---|---|
| Chris | Peoples | NC North Carolina DOT | Raleigh | NC | USA |
| David | Powers | Ohio DOT | Columbus | Ohio | USA |
| Timothy | Ramirez | Pennsylvania DOT | Harrisburg | PA | USA |
| Taina | Rantanen | Sito Oy, Finland (consulting firm working with the ministry | Tampere | | Finland |
| Rick | Rowen | South Dakota DOT | Pierre | SD | USA |
| Mike | Santi | Idaho Transportation Dept.DOT | Boise | Idaho | USA |
| Greg | Schieber | Kansas DOT | Topeka | Kansas | USA. |
| Scott | Schram | Iowa DOT | Ames | IA | USA |
| Joe | Schroer | Missouri DOT | Jefferson City | MO | USA |
| Cliff | Selkinghaus | South Carolina DOT | Columbia | SC | USA |
| Eileen | Sheehy | New Jersey DOT | Trenton | NJ | USA |
| Matthew | Strizich | Montana DOT | Helena | Montana | USA |
| Seyed | Tabib | Ministry of Transportation of Ontario | Toronto | Ontario | Canada |
| Darin | Tedford | Nevada DOT | Carson City | Nevada | USA |
| Curt | Turgeon | Minnesota DOT | Maplewood | Minnesota | USA |
| Jeff | Uhlmeyer | Washington DOT | Olympia | WA | USA |
| Kevin | VanFrank | Utah DOT | Salt Lake City | Utah | USA |
| Brian | Ward | Nova Scotia TIR | Fall River | Nova Scotia | Canada |
| Mark | Woods | Tennessee DOT | Nashville | TN | USA |
| Chunying | Wu | Jiangsu Transportation Research Institute, China | Nanjing | Jiangsu | China |
| Peter | Wu | Georgia DOT | Forest Park | GA | USA |

| | | | | | |
|---|---|---|---|---|---|
| Zhengqi | Zhang | Chang'an university | Xi'an | Shanxi | China |