Utilizing Warm Mix Technologies in Rubberized Asphalt Pavements

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ABSTRACT. Asphalt rubber has been successfully used in the United States since 1960s. Asphalt Rubber is produced by mixing a crumb rubber modifier (CRM) from waste tires with base asphalt binder. Asphalt rubber field blend is a wet process with agitation and normally requires higher mixing and placement temperatures than other binder types. The major applications of rubberized asphalt in the United States include rubberized hot mix asphalt (RHMA), asphalt rubber chip seals, and asphalt rubber interlayers. All three types of applications have higher ambient temperature requirements than other binder types. Various warm mix technologies have been used in California with these products to reduce the cool weather constrains of night time paving with asphalt rubber applications, and to increase the quality of RHMA with higher compaction.

The overall field testing and research results demonstrate there are a wide range of benefits by using warm mix technology with RHMA. These benefits may include reduced fuel usage and emissions, compaction aid, longer paving season, night time paving with cooler temperatures, utilizing long hauling distances, and improved working conditions. More RHMA projects have been placed after the successful experiences with the trial studies that began in 2006. In 2011, there was more than one million tons of RHMA warm mix placed in the northern California alone. Many of these projects were paved at night with cooler temperatures and with excellent results.

KEYWORDS: *Asphalt Rubber, Warm Mix, Rubberized Hot Mix Asphalt, Waste Tire*

1. Introduction

California began using warm mix technologies for rubberized hot mix asphalt since 2006. Because the production and paving temperatures with warm mix technology can be significantly lower than conventional AR mixes, the potential savings in energy and reduction in emissions could be great.

Warm mix asphalt (WMA) is the name given to certain technologies that reduce the production and placement temperatures of asphalt mixes (*1*). Generally, the production and placement temperatures should be between 185 °F (85 °C) and 275 °F (135 °C) for an asphalt to be considered warm mix asphalt (*2*). In the United States, WMA is a relatively new technology. In 2004, the first field trials were completed in both Florida and North Carolina (*3*). Since then, WMA has been used extensively in the USA.

California had its first field testing project using WMA in 2006. The University of California Pavement Research Center (UCPRC) completed the “first phase of a comprehensive study into the use of warm-mix asphalt” for Caltrans in July of 2008. The results confirmed that using the warm mix additives lowered the production temperatures by 35 °C (60 °F) as well as providing many other benefits (*4*). The UCPRC conducted the second phase of lab testing and third phase of Heavy Vehicle Simulation (HVS) study on WMA with AR techniques in 2010. During 2011, Caltrans placed more than 1 million tons of WMA and 32 percent of the tonnage was with asphalt rubber.

There are a wide range of benefits that are reported by using WMA. Reduced fuel usage and emissions are the two major benefits. Other benefits that have been reported include compaction aides, longer paving season/hauling distances, and improved working conditions (*5*). While there isn’t a range of established values for fuel reduction, of the WMA projects monitored, fuel savings of 20 to 35% are possible (*3*). The level of emission reduction varies upon several factors including the amount of temperature reduction, aggregate moisture content, and reclaimed asphalt pavement (RAP) usage. In California, we also note the emissions drop dramatically when used with asphalt rubber (AR) binders.

The benefits associated with warm mix asphalt rubber (AR) chip seals are similar to those reported for WMA. A hot application of warm mix asphalt rubber binder can be applied at a lower temperature which produces lower emissions at the plant and at the job site. The lower emissions equates to a healthier work environment for both the equipment operators and the laborers. The ability to apply the chips to the binder at a lower temperature with the warm mix alternative increases the time window for a successful chip application. The lower application temperature of a warm mix AR chip seal can also extend the total construction season compared to a non-warm mix alternative. The warm mix AR chip seals offer a less expensive maintenance treatment than a thin blanket HMA overlay, plus a much short construction time.

The objectives of this study were to evaluate the feasibility of using warm mix technologies for AR hot mixes to determine whether these technologies will allow operations at lower temperatures without harming the performance of the mix, as well as to determine the effect on mix performance.

2. Types of Warm Mix Technologies

There are multiple warm mix technologies being marketed in the United States at this time (*6*). The technologies can be grouped into technologies that use one of the following:

- Some type of organic additive or wax
- A chemical additive or surfactant
- Water for foaming

Some of the processes used in the United States to date are summarized in Table 1. Most of the current information on warm mixes can be found at the web site located at www.warmmixasphalt.com . Table 2 lists typical production and paving temperatures for some warm mix technologies.

TABLE 1. ***Example WMA Technologies Used in the United States***

No	Supplier-Product	Type of Additive	Web Address
1	Akzo Nobel Rediset WMX	Chemical	www.surfactants.akzonobel.com
2	Arkema Group CECABASE RT	Chemical	www.cecachemicals.com
3	Aspha-min GmbH	Foaming	www.aspha-min.com
4	Astec Industries Double Barrel Green	Foaming	www.astecindustries.com
5	BP Bitumen (WAM Foam)	Foaming	www.shell.com/bitumen
6	Gencor Industries Green Machine	Foaming	www.gencorgreenmachine.com
7	Mathy Technology and Engineering Services, Inc. (Revix)	Chemical	www.mathy.com
8	Herman Grant Company HGrant Warm Mix System	Foaming	www.hermangrant.com
9	Iterchimica Qualitherm	Chemical	www.qprshopworx.com
10	Maxam Equipment Inc. AQUABlack Solutions	Foaming	www.maxamequipment.com
11	McConnaughay Technologies	Foaming	www.mcconnaughay.com

12	MeadWestvaco Asphalt Evotherm	Chemical	www.meadwestvaco.com
13	Meeker Equipment Inc. Aquablack Warm Mix Asphalt	Foaming	www.meekerequipment.com
14	PQ Corporation Advera WMA	Foaming	www.pqcorp.com
15	Saso Wax Americas, Inc. Sasobit	Organic	www.sasolwax.com
16	Shell Thiopave	Chemical	www.shell.com
17	Tarmac Inc. Tri-Mix Warm Mix Injection	Foaming	www.tarmacinc.com/equipment.php?cat=80
18	Terex Roadbuilding Warm Mix Asphalt System	Foaming	www.terexrb.com

TABLE2. ***Typical WMA Production and Paving Temperatures***

WMA ADDITIVES	**Production Temp(°F/°C)**	**Paving Temp (°F/°C)**
Double Barrel Green	250-275 / 121-135	~235 / 113
Evotherm™	180-250 / 82-121	160-240 / 71-116
Rediset WMX	~265 / ~129	~225 / 107
REVIX	245-265 / 118-129	205-225 / 96-107
Sasobit	200-280 / 93-138	150-250 / 66-121
WAM Foam	212-248 / 100-120	176-230 / 80-110
Zeolite	~275 / ~135	>212 / >100
RHMA	325-375 / 163-191	285-350 / 141 - 177

Note: Temperatures were found from the following sources: (*4*), (*7*), (*8*), and (*9*).

The processes which use organic additives or waxes exhibit a decrease in the viscosity when heated above the melting point of the wax, allowing for mixing and coating. The processes using surfactants work via a variety of different chemical mechanisms. The processes that consume water utilize the volume expansion due to the conversion of liquid to gas/steam which causes an expansion of the asphalt binder resulting in a decrease in mix viscosity. The water can be introduced through a foaming operation or by using a material containing internal moisture, such as clay zeolite, or from moist aggregate.

The choice of which WMA process to use depends on several factors. One consideration is how many tons of mix will be produced. Some of the processes have higher initial costs. Others that use chemical or wax additives have higher costs per ton of mix produced than those that use only was to achieve a foaming process.. Another consideration is how much temperature reduction is required since some processes offer more temperature reduction than others. Some additives can affect the final PG binder grades. Typically, both the high and low PG binder grades are affected.

3. Asphalt Rubber with Warm Mix

Asphalt Rubber (AR) has been used in asphalt mixes since as early as the mid 1960's when it was pioneered by Charles H. MacDonald of the city of Phoenix, Arizona, to be used in their chip seal program for the city's streets. Since Arizona DOT fully implemented their rubber asphalt program in 1988, they have used more than 4.2 million tons of asphalt rubber which results in the recycling of 15 million old tires (*10*).

California has also been a major user of AR since the 1980's and currently places about 30 % of all its HMA which includes AR. The use of asphalt rubber has proven to reduce the traffic noise level and delay pavement cracking. This benefit is evident in colder environments where normal asphalt pavements experience early cracking at a higher rate. By introducing rubber into the asphalt, the increased flexibility of the RHMA has reduced reflection cracking by 20% (*11*).

Given the benefits of using rubber asphalt, there are qualities that make it less attractive to utilize. Including the addition of rubber into the asphalt reduces the workability of the mixture. This, in turn, results in higher mixing and compaction temperatures to achieve the desired workability (*12*). The higher temperatures for production and placement for asphalt rubber can also only be limiting due to air quality restrictions. Some air quality districts may only allow up to 1,000 tons per day of AR HMA because of restrictions for maximum allowable emissions (*13*).

However, with the implementation of WMA, these problems should be minimized. Both the production and compaction temperatures of asphalt rubber can be reduced considerably. While the temperatures of rubberized warm mix asphalt mixture (RWMA) are outside of the definition of WMA, 185°F(85°C) and 275°F(135°C), the warm mix technology helps reduce the odor and smoke coming from the asphalt mixture. This temperature reduction also reduces hot plant fuel usage and emissions, allowing more asphalt rubber to be produced without exceeding the maximum allowable emissions.

Fatigue cracking is due to the recurring traffic load on a roadway. This type of cracking is one of the best indications that the pavement is under repeated stress. A study completed at Clemson University in 2008 (*14*) investigated whether or not if the addition of rubber to WMA would affect the fatigue behavior of the asphalt mixture by comparing it to Rubberized Hot Mix Asphalt (RHMA). The study concluded that combining rubber with the WMA was beneficial because it improved "the rheological properties of both the unaged and the aged binders." It was determined also that the warm mix additives offset the increase of production and compaction temperatures induced by the addition of rubber. The fatigue life is greater for warm mix mixtures that include crumb rubber than the control RHMA mixture. The study also found that much of the fatigue life, stiffness, and cumulative dissipated energy values in asphalt mixtures depends on the type of aggregates used.

A few other agencies are beginning to look at the use of warm mix technologies with asphalt rubber or with terminal blends containing rubber. A RWMA demonstration project occurred in August of 2008 on I-295, between the Rhode Island border and the I-95 interchange. The Orlando Paving Division of Hubbard Construction also installed a RWMA-OGFC along U.S. 27 near the city of Clermont, FL. On U.S. 98, in between Dade City and Lakeland, Florida, an 8 mile stretch of RWMA was placed at 1.5 inch (38 mm) thick by APAC Southeast Inc. (*15*). Another trial project which incorporated crumb rubber and the WMA additive Sasobit® occurred in Newcastle, England, in late November of 2006 (*16*). However, no agency has studied it as much as Caltrans. California's experiences are discussed in the next section.

4. Summary of Projects Using Warm Mix Technologies with Asphalt Rubber in California

California has begun to see an increase in the use of RWMA projects. This is partially due to the fact that by 2013, Caltrans has been mandated to use rubberized asphalt concrete (RAC) for 35% of its total statewide production (*17*). The projects completed to date are listed in order of the year completed in Table 3.

TABLE 3. ***Selected AR with Warm Mix Technologies Constructed in CA***

Road Name	Location (PM: n/n)	Date Constructed	Warm Mix Additive
Santa Clara Rte. 152	Santa Clara	Mar-06	Sasobit
Interstate 5	Santa Nella (105.9/106.4)	Sep-08	Astec DBG &Evotherm
Interstate 5	Orland	May-09	Evotherm
CA-94	San Diego	Jun-09	Advera, Evotherm, Sasobit
SH 70	Marysville	Jul-09	Evotherm
SR-101	Fortuna (54.2/56.3)	Sep-09	Evotherm
SH 99	Sutter County	Nov-09	Evotherm
Various	City of Roseville	Sep-Oct 2010	Engineered

Road Name	**Location (PM: n/n)**	**Date Constructed**	**Warm Mix Additive**
			Additives WMA
Interstate 5	Near Firebaugh, Fresno Co. (PM 37.2 to PM 45.0)	Sep-10	Astech PER & Engineered Additives WMA
SR-99	Sutter (T35.6/39.4)	Jul-11	Advera®
	Sutter (40.9/42.4)		
	Butte (0.0/R3.5)		
SR-1	Mendocino (50.9/58.5)	July-Aug 2011	Evotherm™
I-5	Yolo (R21.5/R23.8)(R27.0/R28.9)	July-Oct 2011	Advera®
	Colusa(0.0/R21.0)		
I-5	Yolo (R14.0/R21.5)	Jun-July 2011	Evotherm™
SR 203	Mono (R0.4/R8.7)	Aug – Oct 2011	Advera®
SR 203	Yuba City, Sutter County (11.2/17.0)	Sep-11	Advera®
I-5	Sacramento (0.0/17.2)	Ongoing	Evotherm™

4.1 Example of Rubberized Hot Mix Asphalt Applications

Santa Clara Project

In 2006 Santa Clara Rte. 152 received a 1.75 inch (44 mm) overlay on the shoulder using 200 tons (181 tonnes) of RHMA-G with Sasobit. The Sasobit was added to the rubber binder and mixed for 45 minutes. There was a recorded drop in the production temperature of 40 °F (23 °C) (from 320°F/160 °C to 280°F/138 °C). The paving took place at night with a 30 minute haul time. After two years, the shoulder still “looked good”. Figure 1 shows the completed shoulder immediately after construction in 2006 and the shoulder condition in 2010. There were no signs of distress after four years shown in Figure 2b (*18*).

a) 2006 After Construction b) 2010

FIGURE 1. ***Finished shoulder for Santa Clara Rte. 152.***

I-5 District 3 (2009)

The project in District 3 occurred along a 9 mile (36 lane miles) strip of Interstate 5, near Orland. The project called for a removal of the existing OGFC asphalt and replacing it with 1.2 inches (30 mm) of RHMA-O. Approximately 18,000 tons (16,329 tonnes) was used for the project along with the WMA additive of Evotherm™. The production temperature started with WMA additive at 320°F (160°C) for the first 200 tons (181 tonnes) paved. The temperature was then dropped to 300°F (149°C) where it remained for the rest of the day with 2,200 tons (1996 tonnes) of mix produced at that temperature. For the next three days, the plant’s starting production temperature was 300°F (149°C) and then dropped the temperature to 290°F (143°C) for the rest of the day. On day five, the production temperature started at the usual 300°F (149°C), and then dropped to 290°F (143°C). At 1:30 pm, the temperature was again reduced to 285°F (141°C) for approximately 200 tons (181 tonnes), then back to 290°F (143°C) for the remainder of the day. At all temperatures, the product was able to be easily placed, with the breakdown temperatures ranging from the specified 285°F (141°C) all the way down to 250°F (121°C), and final rolling temperatures from 235-260°F (113-127°C). There was little to no chunking on the mat or in the windrow, and there was very little smoke.

The binder design was 81.5% PG 64-16 asphalt and 18.5% crumb rubber. Of the percentage of crumb rubber, 75% of that was from recycled tires while the remainder was high natural rubber. With 7.2% rubberized asphalt by dry weight of aggregate, it was estimated that 168 tons of scrap tires were used in the resurfacing of the roadway instead of them ending up in the landfill (*19*). Figure 2a shows the breakdown rolling of the passing lane in the southbound direction. Figure 2b shows that the pavement was in good condition in April 2010.

a) Construction in 2009

b) Pavement condition in 2010

c) Pavement condition in 2012

d) Pavement Condition in 2012

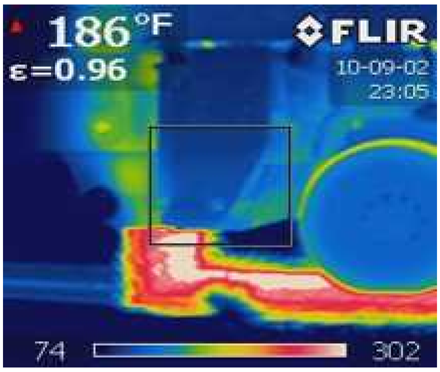
FIGURE 2. ***Pavement condition of RWMA project on I-5.***

4.2 Example of Asphalt Rubber Spray Applications

I-5, District 6 (2010)

This project took place in September, 2010 and includes chip seals for all shoulder areas and rubberized asphalt concrete RHMA-G overlay for both the NB and SB No. 1 and 2 lanes. It was agreed between the contractor and Caltrans to place a trial section of warm mix asphalt rubber seal coat in place of the contracted polymer modified seal coat. The trial section for the warm mix asphalt rubber seal coat is on the NB median shoulder from PM 37.2 to PM 45.0 (12.6 kilometers).

The seal coat consisted of an asphalt rubber binder followed with an application of hot pre-coated chips. The warm mix asphalt rubber consisted of PG 64-16 base asphalt with crumb rubber. The additives included Engineered Additives WMA at 1.5%, and Astech PER at 0.5% by weight of total asphalt binder. The binder was applied at a rate of 0.6 gal/yd^2 (2.8 l/m^2) The chip rock consisted of a 3/8 inch (9.5 mm) pre-coated hot applied screenings and was applied at a temperature of over 300^{o}F (149^{o}C). It was pre-coated with 0.5% of PG 64-16 and applied at a rate of 30 lbs/yd^2 (16.3 kg/m^2).The binder design shows the asphalt rubber binder characteristics for 375^{o}F (191^{o}C), and for 340^{o}F (171^{o}C) with 1.5% WMA additive (*20*). The asphalt rubber binder for the trial section was applied from the distribution truck at approximately 340°F (171°C) and cooled to a temperature of approximately 301°F (149°C) by the time it reached the pavement surface. Figure 3 shows the pictures from the Caltrans D6 project during construction and post construction.



a) Thermal Picture of Hot Chip Application During Construction

b) 3/8 inch Chip Seal Mat, Post Construction, Sept 2010

c) February 2011

d) June 2011

Figure 3. ***Photos of Asphalt Rubber Chip Seal Project on I-5 Shoulder in D6***

The equipment train ran at approximately 3 miles per hour (4.8 kilometers per hour) with 2-sweepers to clean the surface, followed by 2-oil trucks applying asphalt rubber binder. Shortly after the binder application, a Bear Cat chip spreader applied the 3/8 inch (9.5 mm) pre-coated hot chips. The rubber tired roller then rolled the chips into the hot binder. There was about one or two-minutes time lapse between the binder application and the chip application, but it can have a time window of up to 15 minutes due to the warm mix additives.

Some emissions were visible, but were substantially less than when the binder is applied at the typical 400°F. Energy savings were those resulting from lowering the temperature of asphalt rubber for the warm mix binder from 400°F (204°C) to 340°F (151°C). This 60°F (16°C) drop in the asphalt rubber binder application temperature reduced energy use and emissions. The warm mix technology also provides a long time period for chip placement and rolling.

5. Conclusions and Recommendations

Warm Mix Asphalt is a relatively new, innovative technology that is being used to reduce paving and production temperatures of HMA. There are three different categories of the WMA additives: Chemical, Organic, and Foaming (with and without the use of water). Benefits that have been documented when using WMA are: increased worker safety, improved working conditions, reduction in burner costs, reduction in the amount of burner fuel used, reduction in the blue smoke, and an increase in the haul time and paving season.

Depending on which type of additive used, the plant will need to undergo little to no modifications or many modifications. It is up to contractors or engineers to decide which additive they wish to use and modify that plant to accommodate that additive. Some additives require similar or the same modifications. This will enable the plant to produce the asphalt with both additives and possibly obtain more business due to the fact that it can produce both.

Rubber has been used in the asphalt industry since the mid 1960's. Over the years, the industry has recycled millions of old tires by using them in the asphalt, saving them from taking up valuable space in our landfills. Rubber has been more expensive to incorporate in the mix design of asphalt because it requires a higher temperature to obtain the desired workability. However, it has been discovered that by adding a WMA additive to the mix design, the production and paving temperatures are reduced. While they aren't reduced as much as a WMA devoid of rubber, the temperatures can be reduced to a range that makes the use of rubber more cost effective. This can be seen by the increase in the usage of RWMA in recent years, and if these projects yield high-quality results that are equal to or better than HMA, then RWMA will likely be a standard mix for most, if not all, States.

5.1 Conclusions

The results from this study suggest the following conclusions are warranted:

- Warm mix technologies can be used with asphalt rubber mixes. They allow the mixes to be placed at night, in cooler climates, or using longer hauls.
- Warm mix technologies can increase the workability of asphalt rubber mixes. They extend the paving season and allow their use where asphalt rubber could not be used before.
- Warm mix technologies can improve workers' working conditions. They reduce undesired asphalt rubber odor and blue smoke coming with regular asphalt rubber job.
- Warm mix technologies can reduce fuel usage because it reduces the production temperatures by 30 to 80oF (19-45°C). They have energy saving

benefits for asphalt rubber mixes.

- Warm mix technologies can reduce emission at both production and paving procedures. The carbon footprint and green house gas conditions can be improved.
- To date, the initial performance of warm mixes asphalt rubber placed in California is very good.
- The warm mix AR chip seals offer agencies a maintenance treatment for cracked and aged pavements that has a lower construction cost than a one inch thin blank HMA overlay and faster construction.
- The construction time for a warm mix AR chip seal is much shorter than for a one inch thin blanket HMA overlay, and is less disruptive to the motorists and adjacent residents.
- Depending on the actual temperature reduction of the product, the warm mix alternatives may offer as much as an 80% emission savings, plus a sizable energy savings. This emission reduction may equate to huge cost savings in permit fees paid to air quality control agencies.

5.2 Recommendations

Based on the findings to date, the following recommendations are appropriate:

- More agencies should consider the use of warm mixes with asphalt rubber for night time construction and for cool climates.
- More trials should be constructed for using warm mix technologies for spray applications with asphalt rubber and terminal blends.

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