100 Percent Recycling – Sustainability in Pavement Construction

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The Problem

In 2006, it was estimated that there are nearly 8.5 million lane-miles of paved road in the United States (RITA, 2009). The National Asphalt Pavement Association (NAPA) estimates that 94% of the paved roads in the U.S. are paved with asphalt mix. The cost associated with constructing and maintaining these roads is clearly related to the consumer price index (CPI) and shows a similar increasing trend, as indicated in Figure 1.

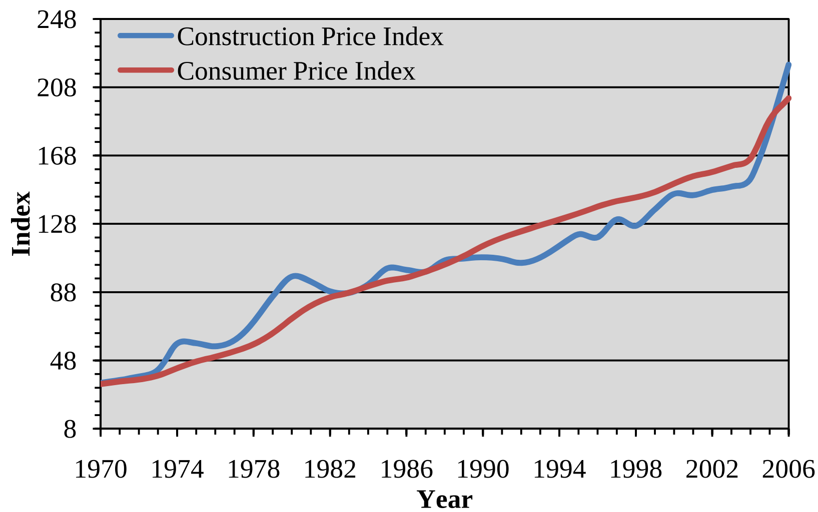

Figure 1: Highway Construction Price Trends and Consumer Price Index (FHWA, 2008)

Hot Mix Asphalt (HMA) mixes typically consist of virgin mineral aggregates and asphalt binder. Asphalt binder is the most costly of the components and is a product of the distillation process of crude petroleum and therefore current pavement techniques are not only reliant on oil for energy but for material too. Besides, vast amounts of mineral aggregates are mined from quarries to build pavements. During production the materials are heated and maintained at a high temperature, which makes the industry heavily dependent on non-renewable energy sources. The use of high temperatures limits the incorporation of reclaimed asphalt pavement (RAP) materials into conventional mix designs. This is because at high temperatures RAP materials tend to produce blue smoke, consisting of air pollutants. These high production temperatures and composition of asphalt binder results in the significant emissions of harmful gases as well.

These factors cause the pavement industry to rely heavily on oil resulting it to be heavily controlled by oil trends. As a result, the pavement industry is always searching for better, more cost and energy efficient as well as environmentally friendly options for building roads. This quest is especially relevant in view of the renewed interest shown by the world community, as reflected in the Kyoto Protocol (Oberthur & Ott, 1998) and more recently, the US President, Mr. Obama's commitment towards working for a better environment (Kennedy-Shaffer, 2008).

The first asphalt road was laid in 1870 by Belgian chemist Edmund J. DeSmedt in Newark, New Jersey (NAPA, 2009). This milestone can be arguably considered the beginning of the asphalt pavement industry; for about 100 years the focus of the industry was to develop “better” performing pavements. It was not until the energy crisis of the 1970’s that environmental considerations were incorporated and recycling of Reclaimed Asphalt Pavement (RAP) material began to appear in the picture (NAPA, 2009). With dwindling natural resources, and spiraling environmental concerns, it is time that the pavement industry reaches another milestone of building roads using 100% recycled materials, with energy efficient and clean technology.

High Temperature and Emissions

Asphalt binders are very viscous (or sticky) at low temperatures. Hence the production temperature needs to be increased, along with the aggregates, to high levels, such as 150^{o}C for HMA, in order to facilitate proper coating and mixing, and also to facilitate lay down and compaction. A major concern, for both the workers and the environment, of working with asphalt binder at high temperatures is the emissions of harmful gases. Heated asphalt binder emits fumes of hydrocarbons and H_2S at an amount that doubles with every 10-12°C increase in temperature (Mallick & El-Korchi, 2009). Furthermore, blue smoke, with tiny droplets of oil, is emitted when aged asphalt materials (RAP) is heated to high temperatures.

During the late 1970s incorporating RAP in to HMA mixes in low concentrations became common; however nearly 40 years later the concentration of RAP in today’s new road constructions and road preservation projects has not been notably increased (Anderson, Turner, & Peterson, 2003). This stand-still state in recycling development is primarily due to the limitations of high mixing temperatures. The exponential relationship between emissions and temperature further necessitates the investigation of options that would allow the lowering of asphalt viscosity at lower temperatures.

Warm Mix Asphalt

The concept of warm mix asphalt (WMA) provides an alternative to using high temperatures. Of the different WMA techniques available, one method is to add specialty products into the asphalt that lowers the viscosity of asphalt even at relatively low temperatures, such as 125°C as opposed to 150°C. This decrease in temperature has three fold advantage; 1. It cuts down the amount of energy required; 2. It decreases the emissions; and 3. It decreases the aging of the asphalt binder during production and hence extends the pavement life.

The implication of using WMA is far reaching. Because of the relatively low temperature required for production and construction, a higher percentage, even 100% RAP can now be used. This will virtually eliminate the need for new virgin aggregates and asphalt binder. The use of 100% RAP recycling will lead to a quantum jump in reduction of energy and emissions and pave the way toward sustainable pavement construction, especially compared to the current incorporation of only 10-40% of RAP. Currently, most state regulations permit a maximum of 30% RAP to be incorporated to HMA mixes (Tao & Mallick, 2008).

WMA technologies in practice are WAM-Foam, Aspha-Min®, Sasobit®, and Evotherm. A study sponsored by the Federal Highway Administration (FHWA) in 2008 investigated European WMA practices and concluded that WMA should be an adequate alternative to HMA with the warning that more research needs to be conducted regarding their performance (Kristjánsdóttir, Michael, Muench, & Burke, 2006).

Table 1: Reported Reductions of European WMA Plant Emissons (Kristjánsdóttir, Michael, Muench, & Burke, 2006)

Country	% Reduction in CO_2 Emissions
Norway	31.5
Italy	30–40
Netherlands	15–30
France	23

Table 2: Reported Reductions of Laboratory Emissions (Mallick et al, 2009)

Temperature	% Reduction in CO_2 Emissions
140	8
130	16
120	24

Table 1 summarizes the reduction of CO_2 emissions found in European plants that had been modified from HMA production to WMA production. The laboratory study, (Table 2), measured CO_2 emission reductions due to a drop in temperatures from HMA production temperatures (150°C) to lower (WMA) production temperatures (Mallick, Bergendahl, & Pakula, 2009). Both studies showed that significant strides towards reducing harmful gas emissions associated with pavement production could be achieved with the use of WMA.

Using the WMA technology, if the amount of RAP in a mix can be maximized, the industry will witness drastic decreases in dependence on conventional energy sources. A popular WMA additive currently in use is Sasobit®. Sasobit® is a wax additive known as an "asphalt flow improver" because it effectively lowers the viscosity of asphalt binder. With a lower asphalt viscosity, the working temperatures can be decreased to WMA temperatures (Hurley & Prowell, 2005). Made by Sasol Wax, Sasobit® is a long-chain aliphatic polymethylene hydrocarbon produced from the Fischer-Tropsch (FT) chemical process with a congealing temperature of 102°C and a melting temperature of 120°C. Sasobit® should be added at a rate of 0.8-3.0% by mass of binder for maximum effectiveness. In general, Sasobit® reduces the rutting potential of asphalt.

Tests show that as mixing and compaction temperatures decrease the rutting potential increases, which could be a result of the binder being less aged (Hurley & Prowell, 2005). There is some concern about the effects of Sasobit® at lower temperatures because below 80°C – 90°C (176°F-194°F) it forms a crystalline network and increases the stiffness of the mix, which can lead to an increased potential of thermal cracking. Suggestions to incorporate a lower grade binder to the RAP to solve this problem have been made (Mallick, Kandhal, & Bradbury, 2008).

Is 100% RAP Viable?

Two preliminary studies have been conducted to evaluate the performance of 100% RAP mixes and the results have proven its feasibility (Tao & Mallick, 2008, O'Sullivan & Wall, 2009). Both studies evaluated 100% RAP mixes combined with very low amounts of virgin asphalt, mixed with Sasobit® or Advera® zeolite.

The results indicate that Sasobit® aided mixes exhibit comparable if not better performance than the mixes without Sasobit®. In the limited studies conducted, Sasobit® shows promise of being an aid to increase the percentages of RAP permitted in today's mixes.
With the aid of Sasobit® 100% RAP mixes showed increased workability, higher moduli, and strengths. This was hypothesized to be a result of the enhancement of the binder stiffness by the Sasobit® (Tao & Mallick, 2008).

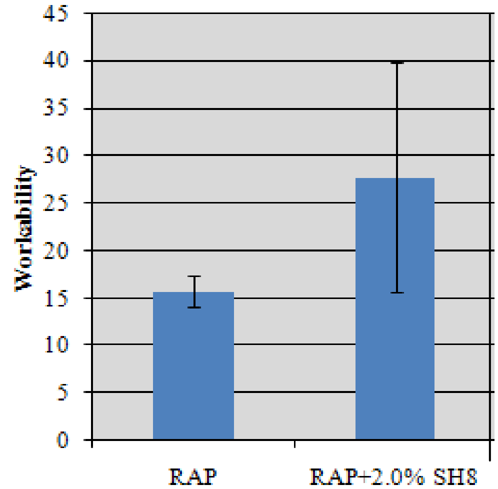

Figure 2: Workability Results of Sasobit® aided 100%RAP Mix (Tao & Mallick, 2008)

Results of a workability analysis of 100% RAP mixes, with and without the aid of Sasobit®, indicated that the Sasobit® aided mix had better workability, as depicted in Figure 2. Both studies exhibited lower air voids during compaction, suggesting increased compactibility when employing Sasobit®. Dynamic modulus (|E*|) testing at a high temperature (37.8°C) and a moderate loading frequency (10 Hz), (Figure 3) and tensile strength tests under unconditioned and moisture conditioned states showed the performance of Sasobit® aided specimens to be significantly better than the control mix (O'Sullivan & Wall, 2009). The study concluded that over-all physical properties were improved with Sasobit® inclusion and recommended further comprehensive analysis.

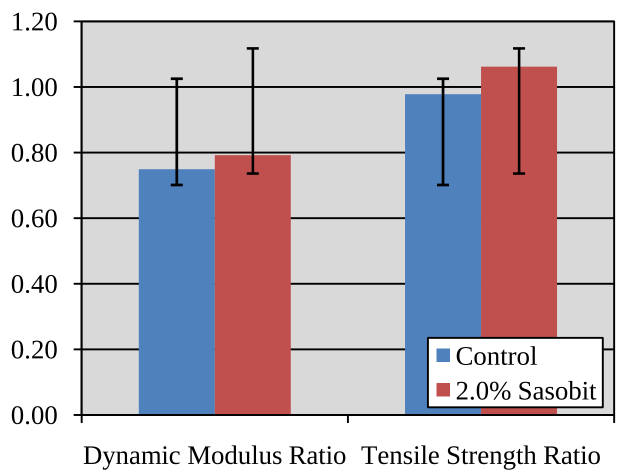

Figure 3: Moisture Susceptibility Results of 100% RAP mixes aided by Sasobit® (O'Sullivan & Wall, 2009)

Laboratory tests on properties suggest that use of 100% RAP is feasible, and that properly produced recycled mixes perform as good as virgin mixes. Cost analysis suggests significant savings with the use of 100% RAP mixes, resulting from savings in materials and energy costs. Overall, it was concluded that the total cost per ton of mix could be reduced by nearly 20% when considering a conventional HMA mix design and methods and a 100% RAP with 1.0% virgin binder aided by 2.0% Sasobit® (O'Sullivan & Wall, 2009). The cost analysis considered both materials and energy costs, as well as cost of Sasobit. The initial cost of plant modifications and training for WMA methods will eventually be offset by the overall savings.

Recommendations

The pavement industry needs to adopt warm mix asphalt (WMA) technologies and increase reclaimed asphalt pavement (RAP) percentages in mixes to reduce cost and environmental impacts. Substantial research needs to ensue within the industry and conclusions need to become readily available to increase awareness. Preliminary studies have shown initial feasibility and warrant further research. The reduction in production temperatures will reduce the amount of energy and emissions, as well as the need for the use of precious natural resources.

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