

Warm Mix Asphalt Paving Technologies: a Road Builder's Perspective

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ABSTRACT

The asphalt paving industry is constantly exploring technological improvements that will enhance the material's performance, increase construction efficiency, conserve resources, and advance environmental stewardship. Current and impending regulations on emissions and energy conservation are making attractive the reductions in asphalt mix production temperature. Warm mix asphalt (WMA) is a means to this end and several systems have been developed including: foaming, emulsions, additives, synthetic binders and others. Warm mix asphalt is produced at temperatures 20 to 40°C lower than hot mix asphalt (HMA).

The immediate benefit of producing and placing asphalt mixes at a lower temperature is the reduction in energy consumption, greenhouse gas emissions, fumes, and odors generated at the plant and the paving site. Furthermore, the technical benefits are substantial including reduction of short term binder hardening, reduction of mixture tenderness, possible increase of percentage of reclaimed asphalt pavement in new asphalt pavement mixes and possible extension of the construction season.

This paper presents an overview of the current warm mix asphalt state-of-practice. A review of the various warm mix asphalt systems is provided. Findings of various studies concerning the observed and measured field performance and the environmental benefits in terms of energy conservation and reduced greenhouse gas emissions are also detailed in the paper.

1.0 INTRODUCTION

The asphalt paving industry is constantly exploring technological improvements that will enhance the material's performance, increase construction efficiency, conserve resources, and advance environmental stewardship. Current and impending regulations on greenhouse gas emissions, fumes/odors and energy conservation are making attractive the reductions in asphalt mix production and placement temperatures. The concept of warm mix asphalt (WMA) is a mean to this end. Warm mix asphalt is produced at temperatures in the range of 20 to 40°C lower than typical hot mix asphalt (HMA).

There is a strong focus on WMA worldwide and several systems have been developed to decrease the bituminous mixture temperatures without compromising the industrial process of producing asphalt pavements. The objectives of these systems are to obtain full aggregate coating at lower mixing temperature, obtain density and still achieve equivalent or better performance than HMA at ambient temperatures. Full coating is obtained by either reducing the viscosity of the binder or by using additives that promote complete aggregate wetting at a lower mixing temperature. Warm mix asphalt systems may be divided into one or a combination of the following categories: water related techniques (foaming and emulsions), additives (organic or chemical), binder mixing technologies and synthetic binders.

The immediate benefit to producing and placing asphalt mixes at lower temperatures is the reduction in energy consumption. With the decreased production temperature come the additional benefits of reduced greenhouse gas emissions, fumes, and odors generated at the plant and the paving site. Furthermore, the technical benefits may also be substantial including reduction of short term binder hardening, reduction of mixture tenderness during compaction, possible increase of percentage of reclaimed asphalt pavement in new asphalt pavement mixes and possible extension of the construction season.

The energy gains due to the reduction in fuel consumption in the drying of material are in the magnitude of 20 % compared to the traditional hot mix manufacturing process. The reduction of greenhouse gas emissions are in the same magnitude as the energy gains. As WMA unveils new possibilities such as increased content of recycled asphalt; the environmental gains are expected to increase. Warm mix asphalt offers an opportunity for the road industry to improve performance, efficiency, and environmental stewardship to achieve global project environmental efficiencies.

This paper presents an overview of the current WMA state-of-practice. A review of the various WMA systems is provided. Findings of European studies, as well as current North American research, concerning the observed and measured field performance and environmental benefits in terms of energy conservation and reduced greenhouse gas emissions, are also detailed in the paper.

2.0 BACKGROUND

The world focus on the development of WMA technologies may be traced back to two distinctive events: the 1992 United Nations' discussions on the environment and the 1996 Germany's consideration to review asphalt fumes exposure limits. The United Nations' discussions resulted in the 1997 Kyoto Accord, which formalized a commitment by the signatory states to reduce greenhouse gas emission to the 1990 levels, while the Germany's review of asphalt fumes exposure limits lead to the formation of a partnership forum (The German BITUMEN Forum) to discuss these considerations. Reduction of mixing and placement temperatures became the obvious answer and triggered the development of WMA concepts and technologies.

The first trials were performed between 1995 and 1999 in Germany and Norway. The first application on a public road was carried out in Germany in 1999 using the Aspha-min[®] zeolite system. The introduction of the WMA concepts and the various systems in Canada are closely associated with the timeline of

outreach activities and field trials carried out in the United States. The first US trials were carried out in the fall of 2004, while the first Canadian trials were carried out in 2005 in Alberta, Ontario and Quebec. Five different systems were tested in Canada in 2005, Aspha-min[®] zeolite, Sasobit, Evotherm, WAM (Warm Asphalt Mix) and Colas 3E DB systems. The first Canadian papers on WMA were presented at Canadian Technical Asphalt Association (CTAA) in 2006. In 2007, trials were carried out in five provinces using seven different processes.

On both side of the border the aspiration and the push for developing warm mix technologies have many similarities with the outreach and technical work of the 90's with SHRP and C-SHRP products. But, dissimilar to SHRP and C-SHRP products, which lead to the usage of PG binders and the Superpave mix-design system, WMA initiatives are not centrally driven and not limited to North America. Consequently, in 2005, an industry/administration technical working group was formed in the US to collect and distribute information on WMA developments and also provide guidance and standardization in field trial data collection. Canada is closely following the work carried out in the US. The outreach and development initiatives remain associated with individual provincial and municipal road agencies, although discussions have occurred at the national level through the Canadian Technical Asphalt Association and the Transportation Association of Canada.

3.0 ENVIRONMENTAL BENEFITS

As indicated in the introduction the obvious and immediate benefit in lowering production and placement temperatures of asphalt mixes is the gain in reduction of energy requirement at the mixing facility. With the decrease in production temperature come the additional benefits of reduced greenhouse gas emissions, fumes, and odors generated at the plant and the paving site, which triggered the development of warm mixes as explained in the previous section. As trials are being carried out, a multitude of paving and technical benefits are unveiled including reduction of short term binder hardening, increased mixture “compactability”, possible increase of percentage of reclaimed asphalt pavement in new asphalt pavement mixes and increased compaction time in more difficult weather conditions.

3.1 Energy Savings and Greenhouse Gas Emission Reduction

Energy savings reported on WMA trials ranged from 20 to 35 % at the plant depending on the WMA system, moisture content of the aggregate and the type/efficiency of the plant. The energy savings may be equivalent to approximately 1.5 to 2.0 litres of fuel per tonne of material. The total energy savings are even greater with recycling. The reduction in greenhouse gas emission is closely associated with the reduction in energy consumption i.e. 20 to 35 % reductions in CO₂ equivalent, which translates into approximately 4.1 to 5.5 kg of CO₂ eq. per tonne of mix.

The “EcologicieL” developed by Colas SA to compare energy consumption and greenhouse gas emissions for various pavement structures indicates that a WMA with 15 % of RAP for the surface course (50 mm) and 25 % for the base course (100 mm) can potentially reduce the total energy requirement by 34.6 MJ which is equivalent to about one litre of diesel fuel per square metre compared to the same pavement structure built with traditional bituminous material (Figure 1). The “EcologicieL” output, shown in Figure 2, indicates that CO₂ eq. emission reduction may be in the range of 2.4 kg/m² for the recycled WMA structure compared to the traditional structure.

Canada consumes approximately 35 to 40 million tonnes of HMA per year; consequently the potential savings in energy is approximately 65 million litres of fuel, which is equivalent to 2,000 tanker trailer loads of fuel. The reduction in greenhouse gas emissions would be in the magnitude of 1.8 million tonnes of CO₂ eq.

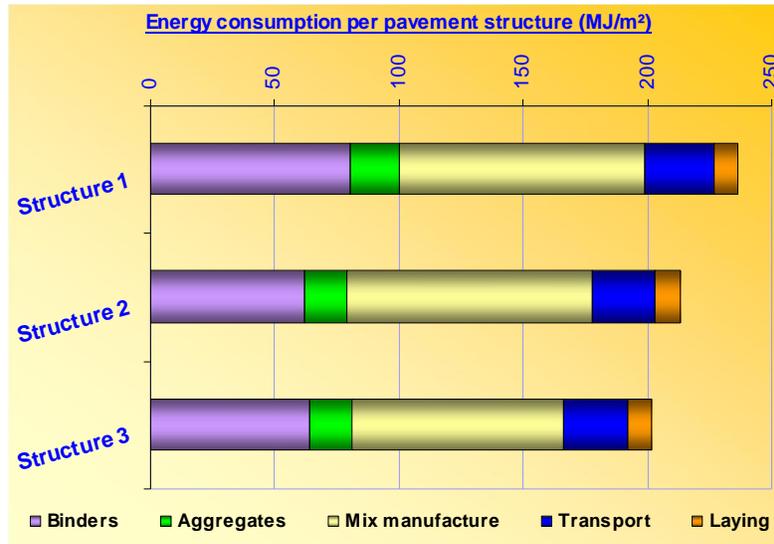


Figure 1 – Output of “EcologicieL” comparing energy consumption (MJ/m²) of traditional virgin HMA (Structure 1), recycled HMA (Structure 2) and recycled WMA (Structure 3)

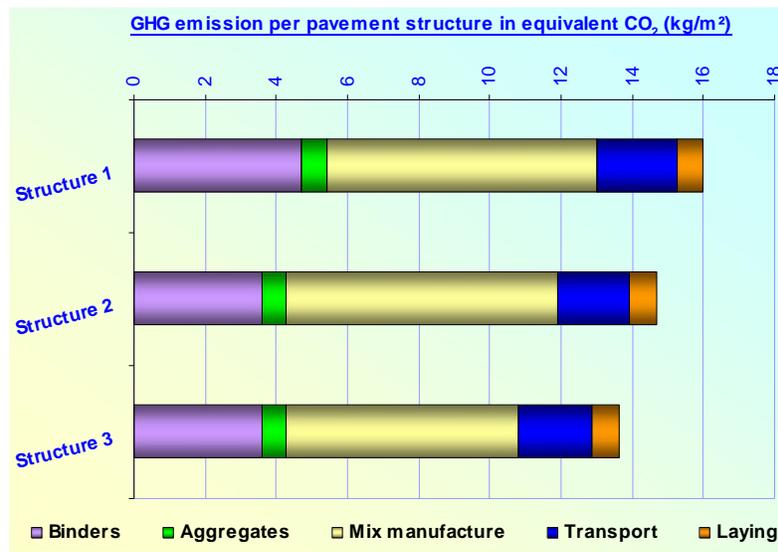


Figure 2 – Output of “EcologicieL” comparing greenhouse gas emission in CO_{2eq} (kg/m²) of traditional virgin HMA (Structure 1), recycled HMA (Structure 2) and recycled WMA (Structure 3)

3.2 Asphalt Fumes Reduction

Lowering the mixing and placement temperatures of bituminous mixes provides enormous gains in reduction of asphalt fumes. Visual observations of WMA during placement clearly show reduction in asphalt fumes (Photo 1). Conservative reports indicate reduction in the magnitude of 30 % while other more optimistic studies are indicating reductions of up to 90 % behind the paver. The German BITUMEN Forum mandated several studies in regards to exposure to fumes and aerosols of bitumen for mastic asphalt and HMA. Studies conducted for the Forum [1] indicate that exposure for WMA mixed at 130°C may be at least half the typical exposure of HMA mixed at 160°C.



Photo 1 – Warm mix asphalt paving operation

4.0 PAVING BENEFITS

Several paving benefits have been reported with WMA including facilitating compaction, transportation, recycling at higher rates, placement of multiple lifts within a short time window and placement of bituminous materials on crack-sealed substrates without the occurrence of bumps.

4.1 Compaction

Warm mix asphalt technologies facilitate compaction. Certain systems have been described as “Flow Improvers” to improve “compactability” of bituminous mixes even in adverse windy and cold weather conditions. The objective of WMA systems is to modify the temperature/viscosity relationship in a manner such that, suitable mixing and compaction viscosities are achieved at lower temperatures, while adequate viscosity is maintained at service temperatures. The concept associated with the modification of the temperature/viscosity relationship of typical WMA systems is provided in Figure 3.

The bracket of temperatures for laboratory compaction for neat binders is often determined using temperature/viscosity charts. The recommended optimal neat binder viscosity for compaction is $.28 \pm .03$ Pa-s (280 ± 30 centistokes) [2]. Compaction time corresponds approximately to the period of time associated with the decrease in temperature between $\sim 140^{\circ}\text{C}$ and 90°C for conventional HMA [3]. There are several factors that may contribute to help compaction: a larger temperature bracket for WMA systems, lower binder viscosity within the compaction temperature bracket and the decreased rate of heat loss at lower temperatures. It is also suggested that a lubrication effect may also be provided with certain additives [4].

The improved compactability of “Flow Improvers” may offer benefits beyond simple ease of compaction in the field. It is put forward that the increased density associated with “Flow Improvers” will lead to better resistance to both, rutting and fatigue. It is even suggested that existing mix-design volumetrics may need to be revised to take full advantage of viscosity reduction and the associated increased density effects of certain types of WMA systems [4].

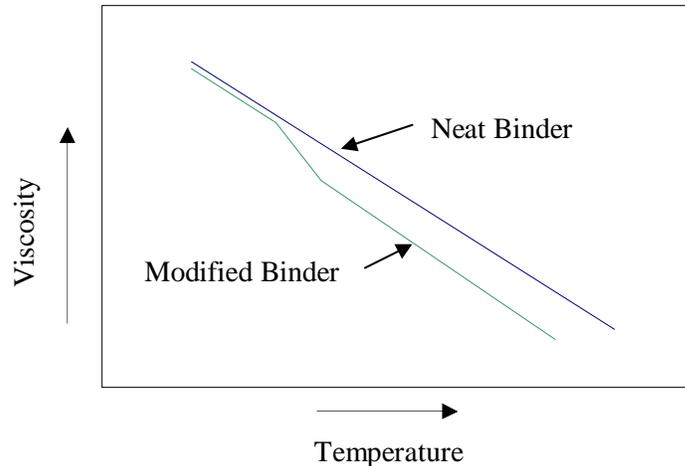


Figure 3 – Modification of binder temperature/viscosity relationship

4.2 Transportation

Warm mix asphalt facilitates transportation. Transportation constraints/distances may impede the placement of conventional HMA mixes. In a sense, transportation time consumes some of the HMA compaction time. This may become a major constructability issue when mixing and placement temperatures are relatively close. Increasing mixing temperature to compensate for long transportation is not viable as increased mixing temperature will likely damage the binder. Warm mix asphalt provides more flexibility; it is possible to increase mixing temperature above the “WMA mixing temperature” (but below the HMA mixing temperature) with limited binder damage. Consequently, mixing temperature may be adjusted to compensate for long transportation time, while workability of WMA remains acceptable at the end of the haul for placement and compaction.

4.3 Recycling

Rate of recycling is strongly influenced by the amount of heat that may be transferred to the reclaimed asphalt. The heat transfer may be “conductive” i.e. super hot aggregate to reclaimed asphalt or “convective” i.e. hot gases to reclaimed asphalt. “Conductive” heat transfer is often preferred since the release of hydrocarbon vapors (“blue smoke”) is limited. “Conductive” heat transfer allows recycling up to ~ 35 % in ideal conditions in conventional batch plants and counter-flow drum mix plants. More heat may be transferred to RAP using the “convective” method using parallel-flow drum mix plants or RAP dryers, but specific emission control systems are required to capture and burn hydrocarbon vapors.

Warm mix asphalt facilitates higher rate of recycling as it may allow more conductive heat to be transferred between super hot aggregates and reclaimed asphalt. In super heated aggregate a certain amount of energy is stored; and as the aggregate comes in contact with the wet cold RAP, energy from the super heated aggregate is transferred to dry up and heat up the reclaimed asphalt. In conventional HMA, the target equilibrium temperature between the super hot aggregates and reclaimed asphalt is typically 160°C, while for WMA the target equilibrium temperature may be typically 30°C lower. Therefore, the lower mixing temperature allows more energy stored in the super hot aggregate to be transferred to RAP. Warm mix asphalt recycling rates in the 50 % range was reported using “conductive” heat transfer [5].

It is noted that the recycling constraints for WMA may differ from those of HMA recycling. It has been demonstrated that the decrease in mixing temperature also decreases the added binder aging. As a result, it is foreseen that the blended binders, RAP binder/new binder, will have properties that may differ from the same blend of binder obtained through the HMA process. It is suggested that the warm mix process

may help the rejuvenation of the RAP binder in a similar manner as if a softer binder was used in the HMA process. As WMA knowledge is acquired it is envisaged that specific WMA recycling guidelines may need to be developed.

4.4 Placement and return to traffic

With most WMA systems the temperature of the bituminous material at the end of compaction is lower than with HMA, and also closer to service temperature. Accordingly, the usage of WMA allows quick return to traffic. For the same reasons, multiple lifts of WMA may be placed on top of one another within a short period of time. This is a net advantage whenever, deep fill of bituminous materials is required to be placed in a trench in a short period of time.

Warm mix asphalt produced with organic additives work differently, but the results are equivalent. Organic additives are referred to as “intelligent fillers” as they provide added flow at mixing and compaction temperatures, and added stiffness at temperature below the congealing (solidifying) point of 100 °C [6]. The rehabilitation of the Frankfurt Airport in Germany is often cited as an example of the benefit of “intelligent fillers”. Deep WMA patches (500 mm thick) were placed within a 7.5 hours time frame with immediate reopening to jet aircraft traffic without pavement deformation.

4.5 Placement over crack-sealed substrate

It has been found that WMA may be placed over crack-sealed substrate with limiting or no adverse effects. The heat from HMA potentially causes an expansion at the crack; thereby pushing the new mat upwards and forming bumps, while the reduced temperature of WMA limits expansion, thus the occurrence of bumps is mitigated.

5.0 PERFORMANCE

The performance data collected in Europe and North America is indicating that WMA will perform equally or possibly better than conventional HMA. The oldest WMA pavement was placed in Germany in the mid 90s’, while the oldest reported section placed in North America has been in service since 2004. Warm mix asphalt is generating a lot of interest worldwide and the research community is decisively at work to provide performance information on various WMA systems. Technical reports are “system specific” but, in general, they all indicate that:

- densification of WMA is improved
- mixture stiffness is not adversely affected
- rutting resistance is not adversely affected
- cure time is shorter
- binder hardening is less
- resistance to thermal cracking may be improved
- moisture damage requires specific attention
- WMA systems may be used with any type of mixes
- effect on binder properties is binder and system specific

5.1 Densification

Several studies have specifically evaluated laboratory and field densification of WMA systems versus the HMA process. It is generally found that equal or higher field densities are obtained with WMA compared to the equivalent HMA mixes. As stipulated above, the objective of most WMA systems is to obtain a binder viscosity that allows aggregate coating at a lower mixing temperature. The target viscosity of the binder for the WMA may be equivalent to the viscosity of the binder for the HMA. However, reducing

the mixing temperature also reduces aging of the binder. Consequently, in field production the binder viscosity of the WMA may be less than the actual target viscosity, therefore favoring densification in a similar manner as if a softer binder was used in the HMA process.

5.2 Binder hardening

Less binder aging has been reported as a benefit of lowering the mixing temperature. A reduced amount of hydrocarbon vapors clearly indicates that less light end portion of the binder is eliminated during the manufacturing process. Two studies related to the Evotherm WMA process [7, 8] indicate that the penetration of the recovered binder after production was significantly higher for the WMA compared to the equivalent HMA mixture. Comparative aging of the binder was also evaluated using the PG system in New York State [9]. The PG of the binder in this particular project was 64-28 and the PG after production was 70-22 for the warm mix and 76-16 for the hot mix asphalt process. The grading of the binder after production was performed without the RTFO aging test for both binders.

5.3 Moisture damage

Stripping is an important performance criterion for any type of bituminous mix. The information obtained on stripping is variable from one WMA system to another. Some reports indicate a slight decrease in stripping resistance, while other reports are not signifying any trends. The consensus in the research community is that moisture damage may be affected by the reduced mixing temperature and/or the type of additive used. At lower mixing temperature the aggregate internal moisture may not be completely removed, which may affect the stripping resistance of the mixture. Nonetheless, as for any type of bituminous mix, the usage of adhesion agents needs to be considered, whenever stripping is identified as a potential problem.

5.3 Binder characteristics

Some binder characteristics may be affected by certain additives, particularly the organic additives. Certain organic additives may have a tendency to stiffen the binder at lower temperature, which may consequently increase the potential for thermal cracking. Furthermore, it was also found that the stiffening effect is binder and additive specific. Nevertheless, the reduced mixing temperature and the resulting reduced aging of the binder may well compensate for the stiffening effect that has been reported for certain organic additives.

6.0 REVIEW OF THE EXISTING WARM MIX ASPHALT SYSTEMS

Until recently, technical papers related to WMA would describe each system in details. This is no longer possible as multiple systems are introduced in the market. Nonetheless, as indicated in the introduction, nearly all WMA systems may be divided into one or a combination of the following categories:

- addition of a small amount of water causing foaming of the bitumen
- bitumen emulsion
- organic additive that reduces the viscosity of the binder
- chemical additive that promotes coating at a lower mixing temperature
- modification of the binder mixing process
- low-viscosity synthetic binder

6.1 Foaming techniques

In the presence of hot bitumen, a small quantity of water (~ 2% by mass of bitumen) changes from liquid to vapour. The expansion ratio of water to vapour is > 1600 at normal atmospheric pressures. The rapid

expansion of the water, from liquid to vapour, creates thin-film bitumen bubbles filled with water vapour referred to as foamed bitumen. In a foam state, the viscosity of the bitumen is reduced allowing full aggregate coating at lower mixing temperatures. The characteristics of foamed bitumen are described in terms of expansion ratio (volume of foam compared to volume of liquid) and the half-life of the foam which provides a description of the stability of the foam in time. Foaming characteristics of bitumen is bitumen specific and foaming process specific.

The WMA systems that use the foaming techniques may be differentiated from one another in the manner that the water is placed in the presence of the hot bitumen. The foaming methods currently on the market include: expansion chambers, wet sand and additives trapping crystallized water. Another process such as blending an inverted emulsion with hot bitumen has been explored in France [10]. Foaming bitumen is relatively simple and inexpensive, and it is expected that other WMA systems will be developed based on that techniques.

6.2 Bitumen emulsion

The bitumen emulsion technique was developed in North America and it consists of mixing a specific high residue bitumen emulsion with hot aggregate at a reduced mixing temperature. As the emulsion is mixed with the hot aggregate the water flashes off as steam. The bitumen emulsion is specifically designed for the WMA process and includes additives to improve coating, workability and adhesion. It has been reported that mixture workability remains excellent at relatively low temperatures ($< 80^{\circ}\text{C}$) [7, 8], which is a specific benefit of this WMA system.

6.3 Organic additives

Organic additives in the form of wax have emerged successfully from an extensive program of laboratory and field trials as a bitumen modifier that enables mixing and compaction at reduced temperatures. Organic additives are often referred to as “intelligent fillers” as they provide reduced viscosity at mixing/placement temperatures and increased viscosity at service temperatures, which is an added benefit specific to this type of WMA system. Furthermore, these additives increase the viscosity of the binder, thus providing increase in resistance to deformation at high ambient temperatures. Technical data also indicates that performance at low ambient temperature is not adversely affected with most binders.

Unfortunately, wax in bitumen is often associated with questionable binder performance. This is an overstatement that may only apply to naturally occurring macrocrystalline waxes present in bitumen in higher concentrations [4]. The research on the beneficial/detrimental effect of waxes on the properties of bitumen revealed that it is critically dependant on the chemical structure of the waxes, of which the full description is beyond the scope of this paper. Waxes used as organic additives for WMA have been specifically selected for their higher melting point (above high service temperatures) and their fine crystalline nature (ability to mix with bitumen).

6.4 Chemical additive

Warm mix asphalt systems involving the use of chemical additives or surfactants are not relying on the reduction of the binder viscosity, but rather the improvement of the coating capability of the binder at a lower mixing temperature. The WMA systems using this approach are relatively new and their development is promising. Certain chemicals are added to the binder in manner similar to anti-stripping agents in a concentration as low as 0.3 % by mass of the bitumen.

6.5 Binder mixing process

Warm mix asphalts may be produced by modifying the binder/aggregate mixing process. Several proprietary processes have been developed, either based on mixing the binder (in foam or liquid state) with coarse and fine aggregates sequentially or based on mixing the aggregate with two different binders (again in foam or liquid state) sequentially. These processes are relatively inexpensive, provided that plant modifications are minor.

6.6 Low-viscosity synthetic binder

Plant-based low-viscosity synthetic binders have been developed in Europe. Mixes produced using these binders are produced and placed at temperatures roughly 40°C lower than conventional HMA. This product qualifies as a warm mix, but it is mainly used for decorative, architectural and ornamental surfacing projects.

7.0 CONCLUSION

Warm mix asphalt is a promising approach to production and placement of paving materials. Research work worldwide is evidently demonstrating that WMA systems are providing significant benefits with regards to the environment, in facilitating paving practices and, with regards to field performance. The response from the paving industry is unprecedented worldwide. In actual fact, it is believed that the development of WMA is impacting and will continue to have an influence on the paving industry in a similar manner as the development of the binder “Performance Grading” and “Superpave” systems of the 90’s.

Significant evaluation work has been completed and the benefits associated with WMA are well documented. However, there is still a significant challenge ahead to move WMA from trial projects to main stream pavement products. All WMA systems are either proprietary processes or based on specific commercial products. Specifications that allow fair competition between the various WMA systems remain to be developed. Systems pre-approval has been identified as an option to facilitate fair competition and purchasing of WMA. It will encourage research and allow differentiation between good innovative products and questionable technology. Even though this is a common practice in certain countries in Europe (Germany and France), this is not how most North American road agencies purchase paving products. The strong desire to move WMA into the main stream of paving products may encourage agencies to specify and purchase pavement products differently.

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