Chapter 10
Warm Mix Asphalt

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Abstract Warm Mix Asphalt (WMA) technologies have potential to reduce the application temperature of Hot Mix Asphalt (HMA) and improve workability without compromising the performance of asphalt pavement. This promises various benefits, e.g. a reduction in greenhouse gas emissions, decreased energy consumption and costs, improved working conditions, better compaction, extended paving season, higher reclaimed asphalt content, earlier opening to traffic, etc. These benefits as well as the potential concerns are discussed in this chapter. Mix design considerations and possible specializations of WMA technologies are summarized. Different WMA production technologies are reviewed with an emphasis on practical applications.

10.1 Introduction

The concept of using lower temperatures to produce asphalt mixes dates back to the 1950s (Vaitkus et al. 2009). The modern WMA was born in Germany in the mid-1990s with the use of waxes as viscosity modifiers for mastic asphalt. Since then a variety of new technologies has been developed in Europe and in 2002 WMA was introduced in the US (D'Angelo et al. 2008). During the last decade the US has become the world leader in implementing WMA technologies (EAPA 2013). Here since 2009 the WMA use has increased by 416 % and in 2012 78.7 million tonnes or 26 % of asphalt mixtures were produced by applying one of the warm mix asphalt technologies (Hansen and Copeland 2013). There are many reasons for such advance, the most important of which are reduced energy consumption, limited emissions, and, perhaps most importantly, improvement in asphalt workability at similar or even lower temperatures compared to HMA.

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In Europe the use of WMA has not become as widespread as in the US and currently only a small portion of asphalt pavements is produced as WMA (EAPA 2012). European countries use WMA more as a niche product for special applications rather than a replacement for conventional HMA. The specific applications often include projects that require improved workability, fast opening times (airfields, night work, junctions), and environmentally critical areas.

The different products fall into one or more of the three general WMA production techniques:

- Foaming technologies, including mechanical foaming and water bearing minerals.
- Organic or wax technologies.
- Chemical additives.

Some of these technologies involve permanent or temporary altering of the binder properties, such as reducing the viscosity. Others rely on improving the coating of aggregates by chemically improving the adhesion between binder and aggregates or introducing surface active agents to improve the aggregate wettability. In the US foaming technologies with the use of nozzles are the most popular among the WMA products accounting for 88 % of the market (Hansen and Copeland 2013). This is likely due to their satisfactory performance and the lowest costs among WMA technologies.

10.2 Overview of WMA

Warm Mix Asphalt technologies use technological advances that allow a reduction in the mixture temperature while improving the workability and compaction when compared to hot mix asphalt. Besides these come multiple other benefits over traditional hot-mix asphalt that, along with some potential concerns, are summarized in this Section in four categories:

- Paving.
- Production.
- Environmental.
- Economic.

10.2.1 Paving

At a given temperature WMA technologies improve workability when compared with hot mix asphalt. Thus they are often used as a compaction aid, to provide the necessary density of stiff mixes. Typically WMA has better workability compared to HMA even at lower temperature. In this case the reduced difference between mix and ambient temperature means the mixture is cooling slower thus providing longer window for compaction compared to HMA. As a result,WMA technologies are often used as compaction aids to ensure cold weather paving, which can extend the paving season or enable night-time and high altitude paving.

Similar to cold weather paving, longer haul distances are possible because mixtures can be compacted at lower temperature. Construction sites a long distance from the plant can be served without losing workability, when WMA technology is used to produce mixtures at traditional HMA temperatures. This means expanded market areas, decreased mobilization cost and accessibility to large urban areas.

Finally, WMA technologies can reduce pavement cooling time if paved at lower temperature. There are reports (Lee 2008) of opening the road to traffic as soon as 2 h after the paving operation. This can be particularly useful at airports, where the time window for construction can be very tight. In a reconstruction project at Frankfurt airport, the existing concrete runway was successfully repaved using WMA and working at night between 10:30 pm and 6:00 am, with the runway temperatures at the opening less than 80 °C (Drüschner 2009).

Software "Multi-Cool" has been developed at the University of Minnesota for the University of California (NAPA 2014). It allows for calculation of optimum paving temperature and the available compaction window based on the environmental conditions and asphalt mixture temperature. It is a useful tool for planning WMA application, especially for cold weather paving.

10.2.2 Production

WMA can be produced with existing asphalt plants by retrofitting the required equipment for a particular technology. One major advantage of production using WMA technologies is the potential to increase the Reclaimed Asphalt Pavement (RAP) and Reclaimed Asphalt Shingles (RAS) content in mixture (Bonaquist 2011a; Zaumanis and Mallick 2013; Kristjansdottir 2007). Since mixture workability is increased even at reduced temperature, less superheating is required for virgin aggregates when adding RAP and RAS. The lower production temperature also reduces the undesirable aging of the already stiff RAP binder.

Some concerns have been recognized for production of WMA as well:

- Residual moisture left from foaming technologies can increase moisture susceptibility (Bonaquist 2011a).
- When RAS and RAP is used in production, the temperature must be sufficient to activate the hard, aged binder (Bonaquist 2011a).
- Plant burners may need tuning to account for lower output due to reduced temperature. This will allow an increase in burner efficiency, reduced fuel consumption, reduced stack emissions and avoiding mixture contamination with liquid fuel. (Harder 2008; West et al. 2014)

- Because of the lower production temperature, the aggregate exposure to the flame in the heating drum can potentially be reduced thus increasing production rate. However, this should be done with caution, because insufficient time of exposure to heat may leave residual moisture in the aggregates and result in insufficient coating of the aggregates with binder.
- The lowered temperatures during production of WMA can lead to condensation in the baghouse which can result in damp baghouse fines and corrosion. The proposed methods to keep the baghouse temperatures high enough are described in details by Prowell et al. (2012) and include:
  - Preheating the baghouse.
  - Insulating the baghouse and ductwork.
  - Removing veiling flights.
  - Increasing air flow by opening the exhaust damper.
  - Adding a duct heater.
  - Installing a variable frequency drive on drum drive or slinger.
  - Ensuring complete aggregate drying.
  - Insulating the dryer shell.

10.2.3 Environmental Benefits

The reduction of production temperature when using WMA and the increased workability of the mixtures provide a potential for significant reduction in energy consumption resulting in lower emissions and reduced carbon footprint of asphalt industry. Reports on the environmental benefits are summarized here.

10.2.3.1 Energy Use

One of the most significant benefits of WMA is the decrease in energy use. Young (2007) has approximated that for every 6 °C reduction in temperature, fuel consumption is reduced by 2–3 %. Figure 10.1 demonstrates results of thermodynamics calculation of energy consumption based on production temperature and another critical parameter, aggregate moisture content. The results of these calculations are confirmed by various practical studies. A scanning report of European WMA production sites demonstrated a 20 to 35 % decrease in fuel use (D'Angelo et al. 2008). Prowell et al. (2012) have summarized the energy consumption from fifteen WMA projects, representing six technologies and report an average measured fuel consumption reduction of 23 %. Similarly, the NCHRP 9-47A draft final report (West et al. 2014) shows savings of 22.1 % for an average temperature reduction of 27 °C at five different production plants. The project results also indicate that the theoretical calculations underestimate the actual fuel savings at an average by 45 %. The additional reduction is attributed to casing losses—heat radiated through the

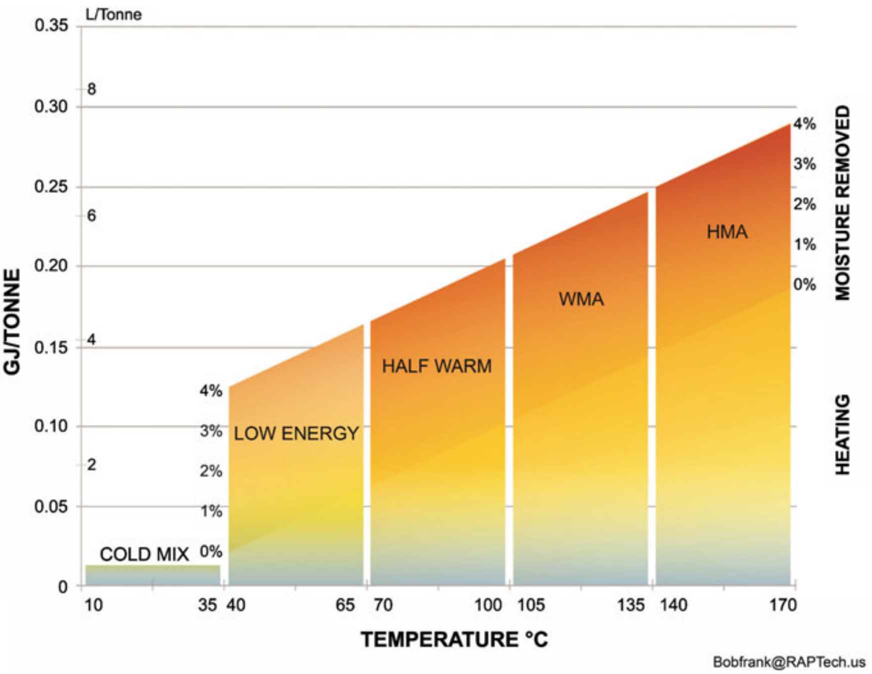

Fig. 10.1 Asphalt production energy consumption (specific heat factors from (WALTOW 2011), kJ/kg-°C: limestone 0.909, granite 0.804, basalt 0.837, sand 0.8, bitumen 1.675, water 4.187, steam 2.01, air 1.005. Latent heat of vaporization for water 2257.2 kJ/kg.) (courtesy of B. Frank)

drum, ductwork, and baghouse or otherwise lost. Zaumanis et al. (2012a) have calculated energy consumption in the entire production cycle and 7 to 18 % reduction in energy use has been reported, with the conclusion that the savings are strongly linked with the production temperature. Practical field measurements have shown that if technologies that allow WMA production close to the boiling point of water are utilized (for example Low Emission Asphalt), the energy savings in production can be greater than 50 % (Prowell et al. 2008).

10.2.3.2 Reduction of Emissions

As expected from the reduction of fuel consumption, the vast majority of reports indicate reduction of CO_2 emissions due to use of WMA. This has often allowed for the use of WMA technologies in non-attainment areas (often large metropolitan areas) where HMA application is limited. The relationship between fuel and CO_2 reductions is shown to be linear (Frank et al. 2011).This concurs with the NCHRP report 9-47A draft that evaluated seven different technologies at three locations and reports an average 20 % reduction in CO_2 emissions resulting from a 21 % reduction in fuel use for a mean temperature reduction of 29 °C (West et al. 2014).

Data provided by UK Carbon Trust (2010) allows calculations which show that switching to WMA production would provide CO_2 savings of 9 %. D'Angelo et al. (2008) reports plant stack emission reduction of CO_2 in the range of 15 to 40 %, SO_2—20 to 35 %; nitrous oxides (NOX)—60 to 70 %, volatile organic compounds (VOC) up to 50 %, and carbon monoxide (CO)—10 to 30 %. Frank et al. (2011), however, notes that the CO and VOC emissions are a part of broader plant practices and may not be directly related to the use of WMA.

The reduced temperature in some cases may require plant burner tuning. As reported in NCHRP 9-47A draft it can be difficult to properly adjust the burner to maintain the optimum fuel/air ratio over the whole firing range. Incomplete combustion will result in both increased fuel use and higher emissions (West et al. 2014). The unburned fuel may cause contamination of the produced asphalt and an increase in the VOC and/or CO emissions (Harder 2008; West et al. 2014).

The reduction of aerosols and fumes is also beneficial to paving crews as visible in Fig. 10.2. Keeping the emissions low is especially important in unfavorable settings like tunnels or underground garages. The results of a study by Kriech et al. (2011) showed average reduction in total organic matter (TOM) of 36 % compared to HMA. The authors also noted that different asphalt binders exhibit significantly different breathing zone exposure levels, thus the effects of lowering the temperature may vary from site to site. A report by D`Angelo et al. (2008) indicate reductions of aerosols/fumes and polycyclic aromatic hydrocarbons (PAHs) in the range of 30–50 %. McClean et al. (2012) reports reduced dermal absorption of polycyclic aromatic compounds (PACs) metabolites when reducing temperature from 154 to 121 °C. It has also been recognized that use of WMA is very beneficial for application of mastic asphalt, polymer or rubber modified mixtures. These types of pavements are placed at much higher temperatures compared to HMA and thus exhibit higher emissions. It has been demonstrated by Spickenheuer et al. (2011) that a 10 °C increase in application temperature results in a 20 % increase in concentrations of vapors and aerosols at the typical mastic asphalt application range of 216–270 °C.

Fig. 10.2 Paving of WMA (*left*) using foaming technology and HMA (*right*)

10.2.3.3 Life Cycle Analysis

Due to the production specifics of WMA, it may promise several benefits that are indirectly related to the reduction of atmospheric pollution. Reduction of fuel used for asphalt production aids in reducing the demand of non-renewable fuel extraction and dropping the carbon footprint of fuel production and transportation. Lowering of bitumen viscosity in the production process allows the incorporation of a higher percentage of reclaimed asphalt pavement (RAP), thus further reducing the need of natural resources. The reduced aging of binder during the production and paving process may increase pavement durability, thus reducing the life cycle cost of WMA (research is ongoing in this area).

There are concerns that some of the environmental benefits may be offset due to the carbon footprint embodied in the production of additives and/or any additional equipment supporting the production of WMA. It must also be realized that the degree of emission reductions depends on the technology used for producing WMA and the type of fuel burned in the process. Additionally, because of the relatively short implementation period, there are still some concerns about the WMA long term performance compared to Hot Mix Asphalt (HMA). If the longevity of the pavement is shorter than that of HMA, the life cycle emissions and also economic costs for WMA will likely negate any benefits that are gained during production. For this reason agencies often require firm proof of the performance of each technology before allowing its use in construction projects.

Use of life cycle assessment tool to calculate environmental effects may be beneficial for showing the environmental effects from WMA use and for comparing different products. Many calculators have been developed for such evaluation. The user must decide what phases of the asphalt life to consider in the calculations. For example, NAPA provides a simple calculator (NAPA 2012) with a gate-to-gate analysis of the asphalt production phase. The user only needs to input the fuel consumption data of the plant and the equipment used. The calculator utilizes its existing database for reporting the emissions as CO_2 equivalent. It also rewards the use of RAP and RAS in mix design. Other calculators could also include the production of raw materials, construction, maintanance of pavement over a pre-defined period, use phase, and end of life solutions. However, care must be given to uncertainties in the calculations that can introduce bias into the conclusions (Capitao et al. 2012).

10.2.4 Costs

The use of WMA, can result in both reductions and increases in production expenses, depending on the circumstances. The calculations should be based on several important variables, which are summarized in this section.

10.2.4.1 Savings

Different techniques of producing Warm Mix Asphalt promise various energy savings for production. The economic benefit from energy savings should be addressed together with the cost and type of energy used, as higher energy prices promise greater savings. Most contractors report a burner fuel usage decrease of 10 to 15 % and savings ranging from $0.10 to $0.80 per ton depending on the fuel type and temperature decrease (West 2013). It is estimated that the production of 47 million tons of WMA in 2010, saved 30 million gallons of fuel worth more than $80 million (Nadau 2012). In the UK, it is estimated that for a typical asphalt plant the WMA technology installation costs are low compared to other means of reducing emissions and the payback period is up to 1 year (Carbon trust 2010). Higher RAP use, which may be realized by the use of WMA, can also significantly reduce the material costs of asphalt mixtures.

Economic benefits should be evaluated together with environmental effects. If stricter emission standards are implemented, there may be higher economic incentive for WMA use. In this case the potential savings may not be immediately quantifiable and should be evaluated together with potential changes in environmental regulations.

Some indirect economic benefits can be ensured in paving process. The ability to work at colder ambient temperatures can extend the paving season thus providing contractors to additional profits. Due to the improved workability contractors are also more likely to reach the required density, thus avoiding the penalties for unsatisfactory compaction. These reduced compaction risks, if realized, can provide longer lasting pavements that can far exceed additional costs for WMA production.

10.2.4.2 Cost Increases

The savings from WMA production may be offset by the additional costs of WMA production. Each specific case must be evaluated to determine if reduced energy consumption will reduce the overall costs of WMA production. Different WMA technologies will require various additional costs depending on the process and existing plant. Increase in costs may arise from (Zaumanis and Smirnovs 2011):

- Investment and the depreciation of plant modification.
- Costs of the additives.
- Costs for technology licensing.

10.3 WMA Technologies

WMA technologies rely on temporary or permanent alteration of binder properties or modification of bitumen-aggregate interaction. The market currently consists of three different production techniques that can be found individually or in combination with each other:

- Foaming technologies, including mechanical foaming and water bearing minerals.
- Organic or wax technologies.
- Chemical additives.

Currently there is no industry standard definition of WMA production temperatures and therefore the classification primarily depends on the user. In practice many contractors produce WMA at temperatures that are very similar to HMA to aid in compaction.

Classification of the technologies by the degree of temperature reduction aids evaluation of the possible energy savings and economic benefits of WMA and allows comparing the temperature reduction potential of specific technologies. Often a temperature reduction of 30 °F (17 °C) has been recognized as the threshold for defining asphalt as a warm mix (FHWA 2012). However, this classification greatly depends on the type of binder used and the mixing temperature of the reference hot mix asphalt. A situation can arise when WMA has a higher production temperature than a different hot mix, for example when a modified binder is used in WMA. For this reason classification by the resulting mix temperature is mentioned in some sources (D'Angelo et al. 2008):

- Cold mix (up to 30 °C).
- Half warm asphalt (65–100 °C).
- Warm mix asphalt (100–140 °C).
- Hot mix asphalt (above 140 °C).

10.3.1 Foaming Technologies

Foaming technologies use small amounts of cold water introduced into the hot binder or directly in the asphalt mixing chamber. This can be accomplished by using foaming nozzles, by adding zeolite, or by introducing a portion of wet aggregates (Zaumanis 2010). The water rapidly evaporates and is encapsulated in the binder, producing large volume of foam which slowly collapses before the binder reverts to its original characteristics (Capitao et al. 2012). The foaming action in the binder temporally increases its volume and lowers its viscosity, which improves coating of aggregates and enhances mix workability. In the foaming processes enough water must be added to cause foaming action, without adding too much to cause stripping.

The properties of the foamed bitumen can be characterized by two parameters (Jenkins 2000):

- Expansion ratio—ratio of maximum volume of foamed bitumen to the original volume of bitumen.
- Half-life—time measured in seconds for the foamed bitumen to subside from its maximum volume to half of the maximum volume.

The optimum foaming water content is generally identified as the amount in percentage of the foamed asphalt content that would achieve the highest expansion ratio and longest half-life. A higher expansion ratio promises larger surface area to coat the aggregates and a longer half-life will provide lower viscosity for a longer period ensuring enough workability of the mixture (Ozturk and Kutay 2013).

Several different methods of introducing water into the mixture have been used. Mechanical foaming uses some type of nozzle (or series of nozzles) as illustrated in Fig. 10.3 to inject a small amount of cold water into the asphalt binder stream. Most water injection systems add 1–2 % water by weight of asphalt binder. The water creates steam which is encapsulated in the binder resulting in foaming and a large volume increase of the binder. This decreases the viscosity thus allowing it to coat the aggregates at lower temperatures (Perkins 2009). The nozzles are computer controlled to allow adjusting the foaming rate.

Another way of foaming the binder is by adding water bearing mineral in the mixture at the same time as the binder. This foams the binder and reduces the viscosity. Finely powdered synthetic zeolite that has been hydro-thermally crystallized (Fig. 10.4) is often used. It contains about 20 % water of crystallization which is released by increasing the temperature above 85 °C. When the additive is added to hot binder a fine mist provides 6 to 7 h of increased workability (Chowdhury and Button 2008; D'Angelo et al. 2008). Zeolites are typically added at 0.25–0.30 % by weight of mixture.

There are two widely used foaming technologies that require additional explanation since they use unique technological processes.

Low Emission Asphalt (LEA) uses sequential mixing technology as illustrated in Fig. 10.5. The coarse aggregate and a portion of fine aggregate are heated to normal HMA temperatures (approx. 150 °C) and mixed with the total amount of binder containing coating and adhesion additives. After the coarse aggregate is coated with the binder, it is mixed with the cold, wet fine aggregate, ideally containing 3–4 % moisture. It results in foaming action that aids in the coating of the fine aggregate (Perkins 2009; D'Angelo et al. 2008). The resulting mix temperature is less than 100 °C. In a drum plant, the fine aggregate can be added through the reclaimed

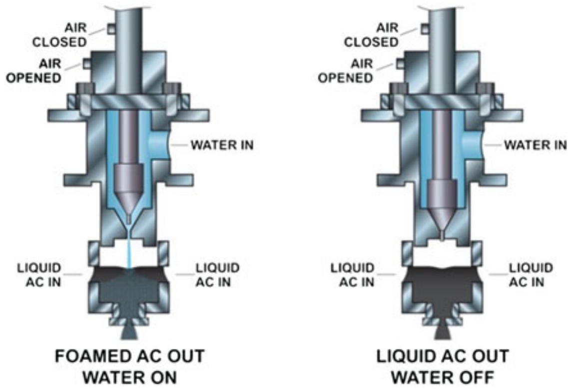

Fig. 10.3 Double barrel green nozzle

Fig. 10.4 Advera zeolite

asphalt pavement (RAP) collar (D'Angelo et al. 2008). LEA-CO has also developed a LEA production kit that can be attached to a batch plant (Chowdhury and Button 2008).

WAM-Foam uses a two component binder system. The aggregate is heated to about 130 °C and then coated with a soft binder, which is typically 20 to 30 % of the total binder. A hard binder at about 180 °C is then foamed into the mixture by adding cold water (2–5 % of mass of the hard bitumen). Initial coating with the soft binder satisfies the asphalt binder absorption of the coarse aggregate that may not otherwise occur with the stiffer binder at a low temperature. At a drum plant the additional binder line is fitted along with the existing line but is not extended deep inside the drum, allowing the soft binder to first coat the aggregate. For a batch plant compressed air must be run through the water expansion chamber after each batch to prevent clogging (D'Angelo et al. 2008; Chowdhury and Button 2008).

10.3.1.1 Production Technology

Foaming system WMA technology producers offer their own production kit that can be fitted to contractors' plants. An example is illustrated in Fig. 10.6. The foaming nozzle must be installed in-line with the binder addition system. It must be supported by a water supply system (water pump, reservoir tank) and water metering system. A bitumen expansion chamber is required in most cases. The water addition processes can be controlled through a control unit from the plant operation center. Special attention should be given to maintain the ability to easily switch between the WMA and HMA production systems. The maintenance of the nozzles is another important issue as they may require special treatment and/or cleaning between the batches or after each production.

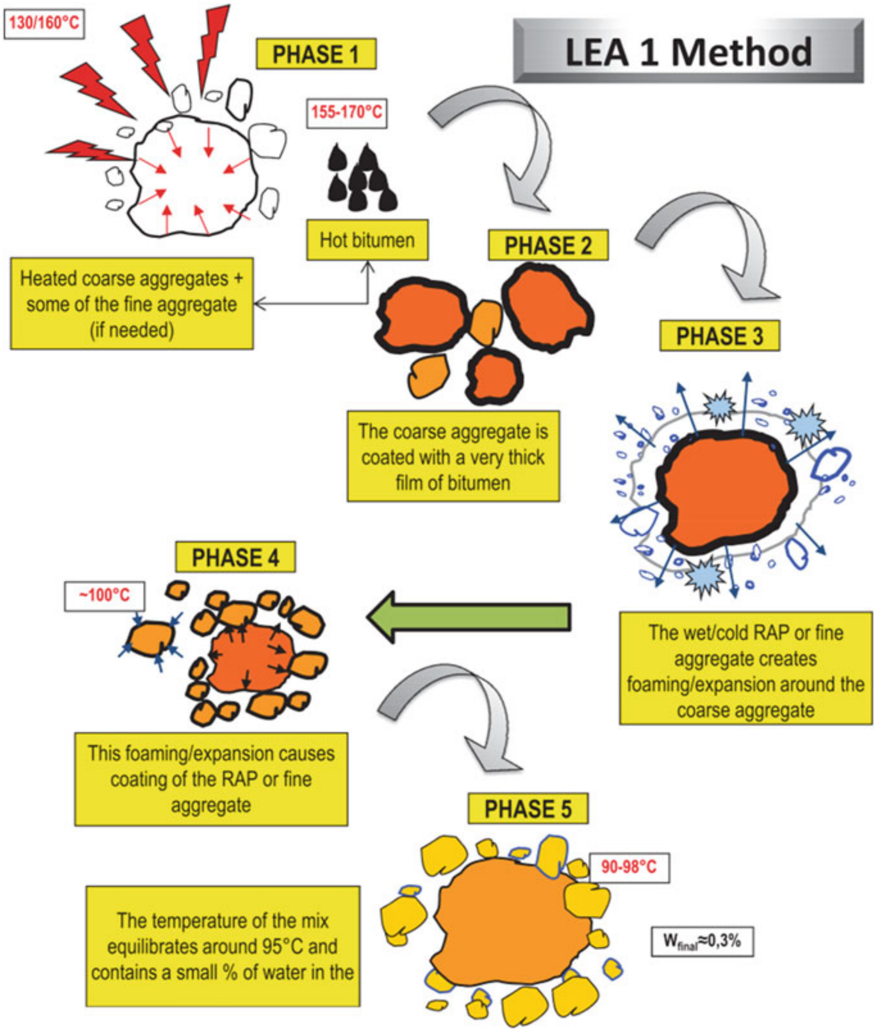

Fig. 10.5 Functional diagram of low energy asphalt (courtesy of LEA)

Zeolite additives in a batch plant can be added into the pugmill using a weight bucket or by blending in line with the binder. In a drum mix plant, they can be pneumatically fed into the drum via the RAP collar or using a specially built pneumatic feeder that introduces the additive in the binder line. The additive develops into a dispersed steam when it comes in contact with hot binder; therefore it must be introduced to the binder directly before addition of the aggregates.

Fig. 10.6 Warm Mix Asphalt System water tank with water pump (*right*) and foam expansion chamber (*left*)

10.3.2 Organic Additives

Above their melting point organic (wax) additives reduce the viscosity and increase the lubricity of binder. In the mixing process this allows coating of the aggregates at lower temperatures, as illustrated in Fig. 10.7. After the pavement has cooled and the additives crystallize, they tend to increase the stiffness of the binder and asphalt's resistance against plastic deformation. The type of wax must be carefully selected to ensure that its melting point is higher than the expected in-service temperature and to minimize embrittlement of the asphalt mixture at low temperatures. A temperature reduction range of 10–30 °C can be expected compared to HMA (Zaumanis 2010).

Sasobit is one of the most widely used organic additives. It is a Fischer-Tropsch (FT) wax in the form of white powder or granulate (Fig. 10.8). It is a long-chain aliphatic hydrocarbon wax with a melting range between 85 and 115 °C, high viscosity at lower temperatures, and low viscosity at higher temperatures. According to Drüschner (2009), with the addition of 3 % Sasobit by binder mass, the binder softening point is decreased by 20–35 °C and the penetration falls by 15–25 1/10 mm. This accounts for the reported increased resistance to rutting of Sasobit-modified mixes (D'Angelo et al. 2008; Chowdhury and Button 2008). In the U.S. the most common introduction of additive is at 1.5 % by mass of binder. Some reports note slightly reduced low temperature cracking resistance when wax additives are used. Qin et al. (2014) report a 2.0 to 3.5 °C increase in the limiting low temperature grade when Sasobit was used at a 1.5 to 3.0 % dose. Other waxes have similar effects on binder as the described product.

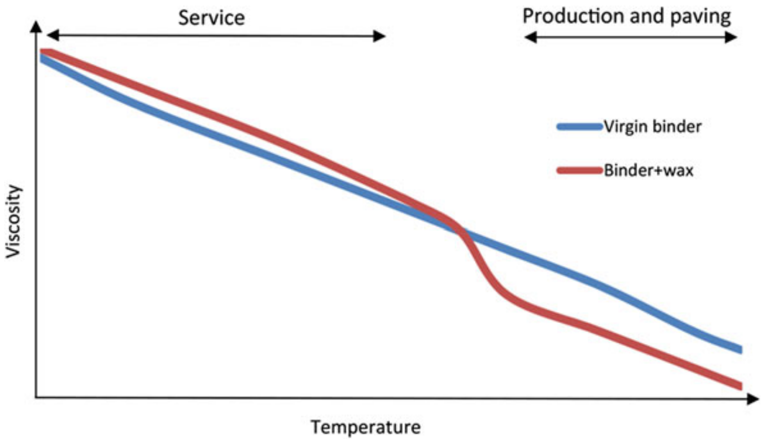

Fig. 10.7 Viscosity change of wax-modified binder

Fig. 10.8 Sasobit addition to binder in laboratory

10.3.2.1 Production Technology

Wax additives are usually delivered in granular form. They can be added to asphalt mixtures in several different ways. The most effective method for ensuring homogeneous mixing is pre-blending with bitumen at a refinery, a terminal, or an asphalt plant. It must be ensured that the wax is stable and stays homogeneous in the binder storage tank. In another method, the wax additives can be heated in a separate tank and injected in a liquid state in-line with the binder addition. The granular form of the additives also allows direct addition of the additive into the asphalt mix using a pneumatic feeder, a weight hopper or an existing fiber addition system. In this case it must be ensured that the additive is homogeneously distributed and well blended with binder. To guarantee this it may be necessary to extend mixing time (especially in batch plants).

10.3.3 Chemical Additives

Chemical additives are the third type of WMA technology that is commonly used. A variety of chemical packages are used for different products. They usually include a combination of emulsification agents, surface active agents, polymers and additives to improve coating, mixture workability, and compaction. These products generally improve the adhesion of binder and aggregates thus eliminating the need for additional adhesion additive. Most additives are designed to not change the grade of the binder. Chemical additives may reduce the asphalt mixing and production temperature by up to 30 °C (EAPA 2010; Capitao et al. 2012).

10.3.3.1 Production Technology

Chemical additives are most often provided in a liquid state and are readily soluble in asphalt binder. This results in relatively minor modifications to the asphalt plant. Additives can frequently be easily added to the binder using existing plant equipment, such as the liquid anti-strip additive in-line injection system. If no such equipment is available, a volumetric pump with a precise metering system can be installed. In some cases the additive may require heating to ensure flow. Liquid additives are mostly stable in the binder and can therefore be added at the binder terminal, or the storage tank at the asphalt plant. A stirring unit for bitumen is necessary if additive is introduced into the bitumen tank. The additive may also be pre-blended by the producer and delivered in the form of bitumen emulsion. Some products are delivered in granular form (Fig. 10.9) and can be added similarly to waxes.

10.3.4 Choosing a WMA Product

In 2013 there are more than 30 products to choose from in the market and the list is constantly increasing. The advantages of using a particular WMA production method can be different from product to product. Therefore, a careful evaluation of the benefits for choosing one method over another for a particular situation is necessary. The critical aspects to consider for choosing WMA technology for the use in specific project are:

- Warm Mix Asphalt performance.
- Cost of the WMA additives and/or equipment.

Fig. 10.9 Rediset WMX granules

- Production and compaction temperature.
- Planned production rates.
- Existing plant equipment.
- Environmental regulations.
- Local performance test requirements.

10.3.5 WMA Technology Acceptance

Due to the rising popularity of WMA, the number of new products is constantly increasing. This requires a standard methodology for the approval of new technologies. The use of WMA should be allowed only if it can provide the same or better mechanical characteristics and long-term performance as HMA. This requirement cannot usually be met by performing laboratory tests alone; therefore field trial with performance monitoring is included. Such requirements have been developed by several agencies and a list of approved technologies is published in some regions. However, the fact that most states require different approaches makes approval of new products costly. A national standard with clear requirements for certification would be very beneficial for increasing competition, and thereby reducing costs of WMA technologies.

The European WMA scanning report (D'Angelo et al. 2008) indicates that in Germany there is an evaluation system to assess and approve new products. This process combines laboratory performance tests and field trials with consecutive monitoring of performance. The trials must meet the following conditions: high traffic volume, right hand (slow) lane, and section lengths of more than 500 m.

During the specified 5 year evaluation period, the sections are monitored for transverse profile, layer thickness, and surface condition. The test sections are constructed in conjunction with a control section.

10.4 WMA Mix Design Considerations

Warm Mix Asphalt has been used in all types of asphalt materials, including dense graded, stone mastic, porous, and mastic asphalt. It has been used with different aggregates, various grades of binder, polymer modified and rubberized bitumens, as well as for producing mixtures containing RAP and RAS. A variety of layer thicknesses and traffic levels have been applied to WMA. Based on these findings, there are generally no restrictions on WMA implementation. There are, however, some considerations regarding WMA design procedures that may be different from HMA and should be taken into account to ensure performance equal to that of Hot Mix Asphalt (HMA).

10.4.1 Binder Content

Mixture designed as WMA, may exhibit less binder absorption due to lower temperatures. Together with increased workability this may result in a lower amount of air voids and, according to mix design practices, require a reduction in binder content. However, there is consensus in the industry that this would result in a stiffer mix that is susceptible to cracking, raveling (Jones et al. 2012), accelerated oxidative aging, and moisture susceptibility. Therefore, the current practice is to use an approved HMA mix design binder content and substitute the WMA process without changes in the binder content. For these reasons the WMA is often designed using the “drop in” method. That is, the mixture is designed according to HMA standard mix design practices and WMA technology is introduced without changes in other mix design parameters.

10.4.2 Binder Grade

As described above, bitumen exhibits less aging in the WMA production process. If the difference in production temperature is very large it may be necessary to bump the high temperature PG in order to compensate for the less aged WMA binder and avoid plastic deformations of the pavement soon after opening to traffic.

NCHRP report No.691 (Bonaquist 2011a) recommends considering an increased high performance grade if the difference in PG between the binder extracted from HMA and WMA exceeds 3 °C. Since various binders exhibit different susceptibilities to aging, a fixed reduction in temperature for which the binder grade should be increased cannot be determined. For a typical binder with average aging susceptibility, a temperature difference between HMA and WMA production temperatures of more than 30 °C would require a change in the high binder grade. The same report suggests that the low temperature grade should not be altered, since changes between HMA and WMA in resultant low PG temperature are relatively small.

10.4.3 Mixing in Laboratory

Laboratory mixing of WMA with organic and chemical technologies does not require modifications, other than the addition of the right amount of additives. There are two methods of introducing additives into the mixture:

- Addition to binder before mixing with aggregates simulates pre-blended binder.
- Adding additives together with binder simulates the in-line addition process.

Production of WMA with foaming technologies in the laboratory is rather challenging and three production technologies can be distinguished:

- Foaming additives can be introduced to aggregates together with binder and will offer a limited time of improved workability. Precaution must be used because of the water steam in the process.
- Water injection with nozzles is technology dependent and will vary by type of nozzle, addition rate, water pressure, etc. There are several commercially available foamers for simulation of this process (Fig. 10.10) albeit precise replication of the full-scale operation is challenging.
- Sequential addition of materials to simulate processes of WAM-Foam and LEA may be impossible in the laboratory because of an inability to simulate the strict full-scale technological operations in the laboratory.

Fig. 10.10 Wirtgen WLB 10 S (*left*) and Pavement Technology's The Foamer (*right*) laboratory foaming units

10.4.4 Production and Compaction Temperature

For normal paving grade binders the production technology can be determined based on the required binder viscosity. WMA technologies use various methods to increase the binder workability, improve “wettability” of aggregates and “lubricity” of binders. Therefore evaluation of the binder alone will not enable determination of the optimum compaction temperature. Moreover, WMA processes are often hard to replicate in the laboratory which means the optimum mixing and compaction temperature should preferably be determined in field conditions.

One method for determining the optimum temperature in laboratory is by comparing the bulk density of reference HMA with that of WMA at different temperatures but equal compaction forces. The temperature at which both densities are the same can be determined. This can be defined as the optimum compaction temperature. This is illustrated in Fig. 10.11. However, the Superpave gyratory compactor has been recognized as relatively insensitive to temperature changes and therefore may not be suitable for this purpose (Hurley and Prowell 2006).

If RAP or RAS is used in the mix design the minimum production temperature must also be adjusted to facilitate melting of the hard binder. To ensure sufficient mixing of virgin and aged binders NCHRP project 9-43 (Bonaquist 2011a) suggests to limit the minimum WMA paving temperature above the high temperature Performance Grade (PG) of RAP or RAS. The same project showed that PG of RAP recovered binder typically does not exceed 94 °C, meaning that most warm mix technologies allow incorporation of RAP at the producer specified WMA temperature. However, the recovered high PG temperature for tear off shingles can exceed 130 °C, thus potentially limiting the reduction of temperature.

10.4.5 RAP and RAS Content

Due to the binder viscosity reduction in WMA, stiff mixes, such as those containing a high percentage of Reclaimed Asphalt Pavements (RAP), can be made easier to work with. The reduced viscosity is beneficial to the workability of the mixture and

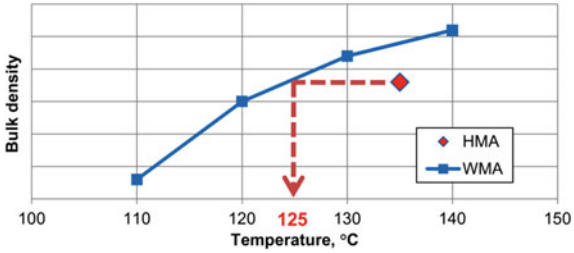

Fig. 10.11 Example of determination of compaction temperature from bulk density

the decreased aging of the binder compensates for the stiffer RAP binder, reducing the cracking potential. According to the NCHRP research project No. 691 (Bonaquist 2011a) the RAP amount in an asphalt mixture can be increased by 10 % if, due to the reduced oxidation, the low performance grade is 0.6 °C lower than that of conventional asphalt. For a typical asphalt binder this can be achieved through a reduction of the production temperature by 28 °C.

It was reported by NAPA research (Gandhi 2008) that for mixes containing high percentages of RAP, the compaction effort was reduced by 40 % when using Sasobit. In Germany, a study (D'Angelo et al. 2008) was presented in which 45 % RAP was used in the base course containing Aspha-min WMA. In the Netherlands LEAB Warm Mix Asphalt is routinely produced with 50 % unfractioned RAP (D'Angelo et al. 2008). A study in Maryland (Kristjansdottir 2007) concluded that the use of Sasobit allowed an increase in the amount of RAP from 25 % for HMA to 45 % for WMA. A course of 5 km was placed and it was estimated that the financial benefits of a higher RAP content can compensate for the additional costs of the WMA technology.

10.4.6 Laboratory Aging

It is recognized that while the physical properties of binders may initially be the same, their properties change when exposed to heat and other external factors. Short term aging occurs during mixing with aggregates, transportation and the laying processes. If the WMA mixtures are produced at significantly lower temperatures the aging may be reduced. Moreover, there are evidences (Lee 2008) showing that short term laboratory aging is more critical for WMA as compared to HMA and can influence the testing results to a large extent.

The NCHRP report 691 (Bonaquist 2011a) suggests using 2 h aging (instead of the four used for HMA) at planned field compaction temperature before running performance tests, which is supported by other research (Hurley and Prowell 2006). These conditions are believed to more closely simulate actual aging during production than the conventional HMA aging of 4 h at 135 °C according to AASHTO R30.

For the products that involve foaming actions to reduce bitumen viscosity and allow better workability of the mix, additional aging time may be necessary to allow dissipation of the added moisture before performing the tests.

10.5 Performance

The performance of WMA, like that of HMA, can vary based on specific application circumstances, such as mix type, WMA technology, and production temperature. This section broadly presents general tendencies of WMA performance as compared to a similar HMA.

10.5.1 Density

Because of lower initial temperature warm mixes cool at a slower rate than HMA which provides a longer compaction window. The pavement in most cases also requires a smaller compaction effort even at a reduced temperature. However, the periods of mix tenderness are also generally longer and may require holding back the breakdown roller (Jones et al. 2012). For example, in Germany 3 % Sasobit was used for WMA and after only one roller pass at a 125 °C a compaction of 96 % was obtained (D'Angelo et al. 2008). The benefit of better workability has also been used for stiff HMA to overcome problems with reaching the desired compaction degree. In Massachusetts Sasobit was used as a compaction aid (Mogawer and Austerman 2008). The target density of 96 % could not be achieved with contractors' equipment. Addition of 1.56 % of Sasobit not only allowed to lower the temperature by 10 °C, but the target density was also achieved using less compaction effort compared to HMA. The rolling, however, must be finished before the wax starts to crystallize to avoid damaging the asphalt binder structure.

In the quality control of eleven WMA field trial sections (Brown 2011a, b) NCAT has not observed major differences in HMA and WMA compactability and the required density was generally achieved with both hot and warm mix asphalt. In Virginia (Diefenderfer and Hearon 2010) field trials with Sasobit and Evotherm included assessment of compaction during a period of 2 years to determine whether further compaction after placement is a problem for WMA. The results show that although the air void content varied, no correlation between time and void content was established and no significant differences between any of WMA sections and control sections of HMA were observed. Similar results are reported by NCAT who has monitored multiple construction sites for periods of 1 to 2 years but has not observed differences between HMA and WMA in-site densification (NCAT 2013).

There have been cases when the WMA technologies have shown lower compaction (Kvasnak et al. 2010; Jones et al. 2008). This is probably connected with the reduction of compaction temperature below workability limits. The air void content for field cores in these two projects was 1.3–6.0 % higher than for the control HMA test section and did not reach the required density.

10.5.2 Moisture Susceptibility

Moisture susceptibility may be an important issue for WMA technologies and in many cases it has been reported different for WMA and HMA even if the same constituent materials are used. There are two reasons for this. If the moisture contained in the aggregates does not completely evaporate during mixing due to low mix temperatures, water may be retained in the aggregate which could in turn lead to increased susceptibility to moisture damage (Jones et al. 2012). This is even more critical for foaming WMA technologies, because of possible residual moisture left behind by the microscopic foaming process. Most research studies report reduced moisture resistance when a foaming process is used (Hurley and Prowell 2006; Jones et al. 2011) and for this reason most foaming technology suppliers advise the use of antistripping additives to improve adhesion. Hydrated lime as well as amines have proven to be effective in increasing the adhesion for WMA mixtures but care should be given to product choice since the lower temperatures used for WMA production may reduce the effectiveness of some antistripping additives (Perkins 2009). NCHRP project 9-43 (Bonaquist 2011a) reports that for WMA mixtures that did not use an antistrip additive the tensile strength ratio (TSR) (according to AASHTO T 283) decreased in 79% of the mixes compared to the control HMA. When adhesion promoter was used, the TSR increased in 67 % of the cases and was never lower than that of HMA. Many WMA chemical technologies already use antistripping additives and therefore eliminate the need for introduction of an additional adhesion agent.

Based on the considerations above, moisture sensitivity testing should always be a part of WMA mix design. The draft for WMA mixture design in AASHTO R 35 standard suggests testing of WMA moisture susceptibility with no modification compared to the HMA test methodology. If the minimum requirement of 0.8 TSR dry to saturated ratio cannot be met, antistrip additives should be used. The Hamburg wheel tracking test in water and the stripping inflection point is another proven method for the evaluation of stripping resistance and the test method is reported to be sensitive to factors that are important for WMA, including binder stiffness, length of short-term aging, compaction temperature, and anti-stripping treatments (Aschenbrener 1995).

10.5.3 Cracking

Because of its reduced production temperature, WMA binder has often not aged as much as HMA and therefore may have improved fatigue and low temperature cracking performance. This may be especially beneficial for mixtures containing RAP and RAS. The less aged WMA binder compensates for the hard RAP or RAS binder, thus reducing susceptibility to cracking.

Due to reduced aging, the low temperature PG may be somewhat lower for WMA compared to HMA extracted binder. Bonaquist (2011b) reports low temperature grade reduction between 0.5 to 3 °C, depending on the technology and production temperature, which promises increased resistance to low temperature cracking of asphalt pavement. However, while Bonaquist's study did not show such an effect, some other studies have reported that the addition of wax might increase the low temperature grade by 2–3 °C (Wanger et al. 2008; Chowdhury and Button 2008) and Fraas temperature by 1–5 °C (Zaumanis et al. 2012b).

NCAT summary of WMA performance in field studies (Brown 2011b) show that in terms of cracking, WMA technologies have performed similarly to HMA between 1 and 5.5 years of age. In most of the eleven evaluated projects there was only small amount of cracking observed in both HMA and WMA. In a St. Louis project a severe reflective cracking was observed for both HMA and WMA. In two projects with Sasobit, slightly more cracking was recorded compared to HMA after 3.5 and 4.8 year of service.

10.5.4 Rutting

Since WMA binder exhibits less aging, the resultant binder is less stiff and thus potentially more prone to rutting early in service life. The exception from this trend is the technologies that use waxes because wax stiffens the mixture at in-service temperatures thus ensuring high rutting resistance. For other technologies reduced rutting resistance has been shown in numerous laboratory studies (Hurley and Prowell 2006; Lee 2008). However, while the laboratory performance in many cases shows an increase in plastic deformations, the actual field rutting resistance has been reported as very similar to hot mix asphalt and generally no rutting problems have been observed. For example, the maximum rutting that was observed by NCAT from thirteen field trials with various climatic conditions and service periods of up to 5.5 years was 6 mm which was equal to the hot mix asphalt control sections (Brown 2011b). The effect of reduced aging on increased pavement rutting is likely limited to applications of thicker WMA pavements (e.g. 120 mm) in hot climates for the first months in heavy traffic (Jones et al. 2012).

Based on the fact that the laboratory performance test results often do not reflect the actual field observations, several US state agencies have reduced their requirements for laboratory rutting resistance when WMA technologies are used. For example, in order to better reflect the warm mix aging, NCHRP report 691 (Bonaquist 2011a) recommends conditioning at WMA compaction temperature and the aging time is reduced to 2 h compared to 4 h for hot mix asphalt. These changes lead to reduced rutting resistance. Therefore, the minimum flow number requirement (rutting resistance criteria) has been reduced to reflect field performance. If the requirements cannot be passed, bumping of binder grade can be considered as disused earlier in Sect. 10.4.2.

10.6 Conclusion

There is a number of benefits from using WMA technologies, including the ability to enhance compaction, reduce the amount of greenhouse gas emissions from production, reduce energy consumption, increase the RAP content, open traffic earlier, pave in cold weather and consecutively increase paving season. These benefits along with competitive costs have caused rapid increase in the use of WMA and most states in the US have adopted specifications allowing WMA use in construction of public roads.

Monitoring of the pavement performance of WMA construction projects has shown that with adequate mix design, production and paving technology, the pavement performance is equal to that of conventional hot mix asphalt. The major considerations for ensuring WMA performance include the necessity of adding adhesion additives to enhance moisture resistance when using foaming technology WMA and accounting for reduced aging in order to avoid the formation of plastic deformations. The “drop in” method for the design of WMA mixtures has proven to be a good choice for ensuring pavement performance. That is, design the mixture as HMA and introduce the WMA process in the production plant.

The upcoming challenges for ensuring WMA quality and encouraging further spread of the technology include developing of a WMA standard design procedure in the laboratory, establishing methodology for determination of the optimum temperature for a particular technology, development of test methods or criteria that reflect WMA in-service performance, and the use of a life-cycle assessment methodology to highlight the environmental benefits of WMA. The procedure for approving new WMA technologies needs to be unified in order to further encourage design of new and better technologies and to increase competition.

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