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AN OVERVIEW OF RECLAIMED ASPHALT PAVEMENT (RAP) MATERIALS IN WARM MIX ASPHALT USING FOAMING TECHNOLOGY

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ABSTRACT

Warm mix asphalt (WMA) technologies that use foaming most commonly used due to their cost effectiveness. This technologies allow the reducing of asphalt binder temperature by adding additives foaming chemical. Civil engineering infrastructure materials can significantly contribute to the sustainability movement through the use of recycled materials and more environmentally friendly production processes. Recycling has been defined as a method by which reclaimed asphalt pavement (RAP) is combined with new aggregate and bitumen or recycling agent to produce hot mix asphalt and obtained by pavement milling with rotary drum cold milling machine or from a ripping/crushing operation. This paper described the feasibility of utilizing Reclaimed Asphalt Pavement (RAP) in Warm Mix Asphalt using foaming technology. Despite the promising performance in comparison with HMA, this technology has not yet gained acceptance in asphalt industry. In order to reach widespread implementation it is necessary to prove that WMA has the same or better characteristics and long term performance as HMA. Besides, it discover whether by the use of foamed warm asphlat additives are possible to reduce the high temperature whilst slower aging of the modified binders and will helps to give better understanding on environmental effect of both human and materials.

Keywords: reclaimed asphalt pavement, foaming, warm mix asphalt, sustainable.

INTRODUCTION

Environmental expert define sustainability as meeting the needs of the present without depleting and reducing the resources required by future generations (World Commission on Environment and Development 1987). Civil engineering infrastructure materials can significantly contribute to the sustainability movement through the use of recycled materials and more environmentally friendly production processes. Recycling has been defined as a method by which reclaimed asphalt pavement (RAP) is combined with new aggregate and bitumen or recycling agent to produce hot mix asphalt (HMA). The RAP may be obtained by pavement milling with rotary drum cold milling machine or from a ripping/crushing operation (Huffman, 2001).

According to Du.J (2007) reclaimed asphalt pavement (RAP) and warm mix asphalt (WMA) have become the primary methods for enhancing sustainability in the asphalt industry in recent years. The development of recycling processes results in a rapid reduction of natural resources and energy as well as leading to search for new sustainable alternative. Over the years recycling has become one of the most desirable pavement rehabilitation alternatives. Based on continuous accumulation of performance data, field and laboratory evaluations of recycled mixes, it is expected that recycling will continue to be the most attractive rehabilitation technique. The choice of rehabilitation technique should be based on energy conservation, economic consideration, engineering consideration, environmental effects (Huffman, 2001), (Du.J, 2007).

In Malaysia, various recycling techniques are adopted for rehabilitation work of flexible pavements. The total extent of Malaysia roads network is approximately total of 137,220 kilometers with 111,378 kilometers of pave road and 25,842 kilometers of paved roads (Bahagian S. F. J., Statistik Jalan 2010, Jabatan Kerja Raya Malaysia). J Ahmad *et.al* (2004) reported that most of the paved roads in Malaysia are flexible pavement. The flexible pavement structures in Malaysia consist typically of bituminous surfacing, granular road base, drainage sub base and the formation subgrade. In every 3 to 5 years, the deteriorated wearing course is disposed of in large volumes in the form of waste and yet, no initiative taken by road builders to use RAP in construction or rehabilitation of highway and roads. Malaysia government should make it mandatory for the road builders rather than optional to use RAP in awarding contracts so that it will help in reducing abundance of reusable asphalt pavement material stockpiled in empty fields or by roadsides and subsequently, lower the cost of building new highway and roads .

Asphalt concrete removal leads to a production of more than 100 t of RAP per year in the United States. While in Europe, engineering and environmental life-cycle cost and benefit are the basis for many of the recycling initiatives (Collins et.al, 1994). Countries like Denmark and Netherland have used 100% RAP meanwhile Sweden and Germany recycled 95% and 55% of asphalt surface material respectively (Holtz and Eighmy, 2000).

The use of RAP also decreases the amount of waste produced and helps to resolve the problems of highway construction material especially in large cities. Performance issues may arise with the use of higher amounts of RAP in terms of pavement durability. According to Xiao et.al (2007) the used of 15% of RAP significantly increased mixture stiffness, which open the door for premature development of various forms of

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pavement cracking. Cracking resistance can be reduced in performance grade (PG) 58–28 mixtures containing up to 50% RAP through disk-shaped compact tension, indirect tensile (IDT) creep compliance, and acoustic emissions tests at low temperatures. The stiffness also increase with containing RAP may lead to the selection of more costly softer asphalt binder and may limit the amount of RAP that can be used in a mixture (Behnia *et.al,* 2010).

D'Angelo *et al*., (2008) stated that WMA represents a growing alternative to conventional hot-mix asphalt (HMA). This technology is produced at temperatures of approximately 25–30°C less than HMA due to chemical composition changes during the mixing process. At least 20 WMA additives and processes exist on the market today, and these include foaming additives and processes, organic additives, and chemical additives. The foaming group uses water to foam the asphalt binder prior to or during the mixing process. The foaming processes subcategory uses water injection systems to foam the asphalt binder, and the additives subcategory includes synthetic zeolites such as Advera and Aspha-min. Synthetic zeolites are metallic aluminosilicates, which contain approximately 20% water by weight in their microstructure (Prowell B.D, 2007).

Liquid chemical additives generally act as emulsifying agents and contain amine groups that lead to improved thermal cracking and moisture resistance, respectively. Several environmental advantages occur with the use of WMA such as energy savings and emissions reductions. WMA also can reduce fuel consumption by as much as 10–35%, as fuel usage may decrease by as much as 3% for each 6°C drop in mixing temperature. European and Canadian researchers have determined that a 15–70% reduction in SOx, NOx, CO2, and volatile organic compounds (VOC's) emissions are generally realized with the use of WMA (D'Angelo *et al,* 2008), (Prowell B.D, 2007).

Potential disadvantages of WMA include increased rutting, moisture sensitivity, and a lack of long-term field performance results. In the case of the chemical and foaming groups, mixture stiffness may be reduced such that rutting resistance. In contrast, organic additives may increase stiffness such that pavement cracking potential increases. The lack of long-term WMA performance data in the field of practice also affects WMA use in the United States; the technology has only been in place for approximately 8 years. As a result, laboratory performance tests continue to fulfill a critical role in the design and deployment of existing and emerging WMA technologies.

RECLAIMED ASPHALT PAVEMENT

Introduction of reclaimed asphalt pavement

In the report of Collins and Ciesielski (1994), RAP is a product of asphalt pavement removal and is the primary recycled material used in asphalt concrete. Milling machines break down the existing asphalt concrete pavement into discrete particles as shown in Figure 1 to produce RAP. It can be estimated more than 100 million tons of RAP are produced every year in the United States. Fractionated RAP (FRAP) is produced to afford extra control over RAP particle size, mastic content, fines, and overall quality. Specifically, the introduction of FRAP has allowed mix designers to meet Superpave mix design volumetric specifications more according to consistently.

Hot Mix Asphalt (HMA) materials are 100% recyclable since studies have shown that materials present in old asphalt pavements which contain both asphalt and aggregates still retain considerable value which can be incorporated into virgin asphalt mixtures. The term Reclaimed Asphalt Pavement (RAP) for these reusable pavements has proven to be economical and environmentally sound with the use of RAP aggregates in highway construction. This has become a widely accepted practice in many state highway agencies in the United States and researched on the properties of recycled aggregates in pavement construction is limited to unbound pavement layers (Brown, 2011)

According to Chiu *et.al* (2008), the use of RAP in asphalt concrete adheres to the requirement of sustainable solutions in pavements because it is both environmentally friendly and cost effective. By adding RAP to mixtures, it reduces the environmental impact of production by 23%. Furthermore, RAP presents a significant material cost reduction. Quality virgin aggregate material is becoming increasingly difficult to find and purchase. Therefore, the use of RAP can offset costs and allow state and federal agencies to rehabilitate more roadways with similar budget capacities.

Illinois Department of Transportation (2011) in the report stated that the addition of RAP to asphalt mixtures is generally limited to a 10-30% range. State agencies such as the Illinois Department of Transportation allow up to 30% RAP in binder and surface mixtures depending upon the traffic level present on a given roadway. As stated previously, RAP is usually considered to be a stiff material primarily due to the oxidative hardening and other aging mechanisms it undergoes while exposed to the environment during its service life. Consequently, the increased stiffness in RAP may lead to various forms of cracking failures which deter producers and state agencies from further increasing RAP allowance (Xiao *et.al,* 2007).

Figure-1. Reclaimed asphalt pavement (RAP) (Chiu, 2008).

Rehabilitation of existing road by recycling of pavement materials can offer environmental benefits include reduced extraction of primary aggregates and disposal of existing materials and reduced haulage of construction materials. The recycling of bituminous surfacing is commonly used to restore the pavement profile, improve skid resistance, and rectify cracking caused by binder hardening according to Austroads and Asphalt Pavement Association Guide (1977)

The author (Shahid, 2000) stated that the wearing course is disposed of in large volumes in the form of waste in every 3 to 5 years. It indicates the replacement of pavement layers will need large quantities of good quality aggregates from quarrying production of these materials. The common operation involves in recycling of pavements involves mixing of the existing milled pavements with virgin material of a modifier. In this study, a preliminary investigation on the degradation of RAP aggregates is carried out to determine the aggregate properties extracted from RAP intended for use with virgin aggregates for a new asphaltic mix. Degradation of the RAP aggregates is focused on the mass of RAP aggregates retained due to method of extraction of the RAP materials. Another important aspect of aggregates for use in wearing course is the strength of aggregates against crushing effect. The RAP aggregates are also evaluated for resistance to crushing to determine the strength after the extraction process and being in service for several years.

Brian Hill (2011) in his report mentioned that RAP is a beneficial alternative to virgin aggregates economically and environmentally. As shown in Figure-2, the milling machine used in this recycling process. This milling machine grind the distressed and aged asphalt pavement into virgin aggregate size particles through the use of system of blades that continuously cut the material. Next, RAP is dumped into a trailer via a conveyer belt on the milling machine. Once the trailer is filled, the material is taken back to an asphalt plant.

Figure-2. Milling of rap process (Brian, 2011).

In paper written by Kandhal and Mallick (1997), the use of 20-50% of this recycled material can save up to 34% of the total cost. This reduction in cost is associated with a reduction in asphalt binder use, virgin material cost, and virgin material transportation. Furthermore, RAP is advantageous due to its environmental impact. As stated previously, Chiu *et al.* (2008) found a 23% reduction in eco-burden due to the reduced amount of asphalt binder required and the amount of energy required to heat the materials. RAP generally supplies a significant amount of asphalt binder which can interact and coat the virgin aggregate material. Pavement performance has the potential to be improved by the use RAP as well. The relative stiffness of the RAP material can improve performance in the area of permanent deformation. At locations such as intersections, PG binder grades are generally increased to avoid rutting issues. However, according to NCHRP Project Report 9-12 by Daneil *et al.* (2000), the use of RAP may inherently increase the binder grade of the asphalt mixture. Therefore, the addition of RAP has the potential to create a rut resistant mixture.

Disadvantages arise with the use of RAP as well. RAP is an inherently stiff material due to the oxidizing effect of sunlight and the atmosphere. According to Xiao *et al.* (2007), the presence of as little as 15% RAP has the ability to significantly stiffen an asphalt mixture. Wagoner *et al.* (2005) found that the fracture resistance of asphalt mixtures was reduced through the use of an increased asphalt grade. Consequently, the addition of RAP, according to NCHRP 9-12, increases the PG grade of the asphalt binder. Therefore, the increased stiffness increases the brittle nature of the asphalt concrete and the probability of brittle failure at low temperatures. Variability among RAP stockpiles is also a significant issue.

Dave (2003) studied the recovered asphalt binder of 16 different RAP stockpiles in Illinois through the use of the Dynamic Shear Rheometer. The complex modulus, G*, of each RAP stockpile was calculated and they found that the complex moduli differed significantly. Therefore, RAP stockpiles must be considered on a case-by-case basis because the stiffness of a given RAP stockpile may require different considerations from a stockpile in a different location.

Extraction process of reclaimed asphalt pavement

Extractions in combination with one of two recovery processes are also needed to evaluate the binder properties of an existing HMA such as an existing pavement or in a reclaimed asphalt pavement (RAP) stockpile. The most commonly used solvents for extractions have been used are methylene chloride trichloroethane (TCA) and trichloroethylene (TCE). However, the terms of the Montreal Protocols and US Clean Air Act require that both CFC and HCFC-based chemical solvents are phased out of use for environmental reasons. Other than that, ignition method widely used compared to solvent method due to hazardous solvent to man and environment.

RAP materials are still valuable even when the pavements have reached the end of their service lives and

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when used with virgin mixtures are found to perform well according to NCHRP Research (2011). The main advantages of these methods are: no calibration factor needs to be determined and the properties of the binder and aggregate extracted from the HMA may be tested after extraction.

Solvent method

Previous researchers conducted by Abson and Burton (1960) and Peterson et.al (1994) found that both the extraction and recovery processes as well as chlorinated solvents can age or harden the asphalt cement . The most commonly used solvents in the past for extractions and recoveries were TCA and TCE. These products were marketed and supplied by two or three large companies with similar manufacturing processes according to Petroferm Inc. Quality. It has been suggested that this resulted in a relatively consistent product, regardless of the solvent source.

Ignition method

Currently, the ignition oven test is described in both AASHTO T308 and ASTM D 6307 standards. The ignition oven uses high temperature to burn the asphalt off the aggregate; the typical test is conducted at 538 °C or 1000 °F. ASTM specifies a test temperature of 540°C or 1000 °F in keeping with their policy of using rationalized unit conversion, so-called “hard conversions.”. During a typical ignition test, the sample is heated continuously until three consecutive readings of the mass of the sample, taken at one minute intervals, do not change by more than a specified threshold level, typically 0.01%. To avoid any segregation, the samples are carefully extracted by quartering on a large tray. RAP samples extracted by full depth method should first be broken down to avoid lumps of aggregates bounded together. Asphalt content tester is another method that be used to determine the binder content from the extraction of RAP.

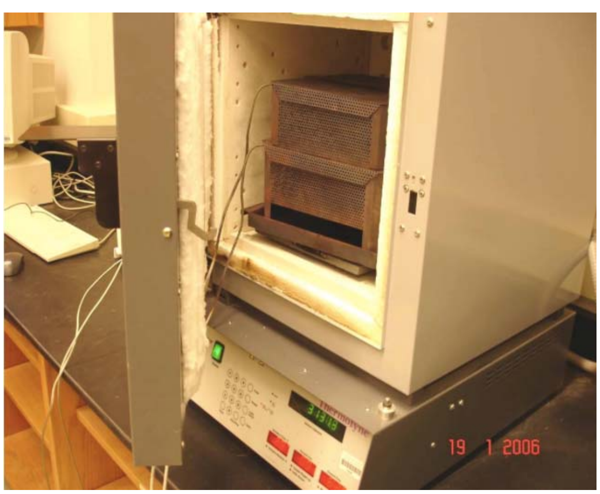

Figure-3. Thermolyne ignition oven.

(a) (b)

Figure-4. Samples of RAP: (a) before and (b) after ignition process.

The calculation of asphalt binder content of asphalt given by:

$$AC\% = \left[\frac{W_S - W_A}{W_S}\right]*100$$

Where:
$AC\%$ = measured asphalt content
W_A = *Total weight* of aggregate remaining after ignition, g
W_S = Total weight of the HMA sample prior to ignition, g

Figure-5. Apparatus of asphalt content testing.

Overview of WMA-potential benefit and drawbacks

Warm mix asphalt (WMA) is a rapidly expanding form of asphalt concrete, although it is somewhat akin to cold mix and warm mix approaches that have been available for decades. It differs from hot mix asphalt (HMA) only in the production temperatures required to meet appropriate standards of mixing and densification. Figure-6 displays the classification of asphalt mixes according to temperature and fuel consumption. As shown, WMA is generally produced 35-55 ^{0}F (20-30 ^{0}C) less than HMA. However, several forms of WMA may allow an additional 20-40 ^{0}F reduction in production temperatures. According to D’Angelo (2008) , described the warm mix asphalt as asphalt mix, which is made in temperature (20-

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30) °C lower than hot mix asphalt, but above water vaporization . In Europe technologies, which allow reducing the hot mix asphalt production temperature in range (10-40) °C, are called warm mix asphalt – WMA

Brian (2011) report that WMA additives and processes can be differentiated into three distinct groups. These groups include: organic additives, chemical additives, and foaming processes and additives. Organic additives involve the addition of wax materials which dissolve at temperatures below the mixing temperature. As a result, the material enhances mixing in its liquid state and hardens after compaction to provide stability. Organic additives tend to improve rutting resistance and reduce fracture resistance of asphalt mixtures. Chemical additives include a variety of chemical packages from surfactants to pastilles. These materials affect the surface bonding between the asphalt binder and aggregate and are most likely to improve fracture resistance and have the potential to increase rutting. Foaming processes and additives use water to foam the asphalt binder and reduce its viscosity prior to or during the mixing period. This group contains the largest variety of WMA methods and tends to increase the potential for permanent deformation and moisture sensitivity.

The discussions about the decrease of the temperature in asphalt production aren't new. The idea to save energy and to reduce emissions in asphalt industry is disputed decades already. In 1956, Dr Ladis H. Csanyi from Iowa State University, realized the potential of foam bitumen for the production of cold mix asphalt. In (1999) K.J. Jenkins introduced the process for the usage of half warm mix asphalt together with foaming bitumen. They researched the possibilities to heat aggregates up to the temperature which is higher than environmental but lower than 100 C before putting in foaming bitumen.

Recent years saw the large amount of experimental laboratory research in which the different experimental sectors were introduced to research the warm mix asphalt technologies. In 2008 in Omsk, Russia, the research was made in the reduction of the temperature for the thickening of layers using Cecabase RT Bio and Cecabase RT 945. Hurley and Prowell (2005) made a research in reducement of hot mix asphalt production temperature using Aspha- min, Sasobit and Evotherm supplements. (Kristjansdottir, 2006), summarized information about the conditions of warm mix asphalt usage in cold climate environment. The most suitable for the Island was mentioned WAM Foam, Aspha-min and Sasobit.

(Tusar, 2008) summarized the reached on hot mix asphalt experimental research made in Slovenia. The research was made in sectors where asphalt layers were built from warm mix asphalt made using Aspha-min and Sasobit technologies. Brosseaud and Jacques, (2008) found that the usage of lower working temperature asphalt mixes in France. They marked the technologies of the half warm and warm mix asphalt mixes. Sasobit, Evotherm and Aspha-min supplements usage in warm mix asphalt and its influence to the asphalt characteristics was analyzed by most researchers. The research publications summarize the warm mix asphalt technologies and emphasize that these technologies reduce the emission of noxious gases and bitumen smoke. Also, warm mix asphalt technologies are more acceptable for the production of recycled asphalt mixes and other asphalt mixes. (Goh and You, 2008).

The most important advantage of producing warm mix asphalt (WMA) is the reduction of energy requirements which consumed a lot of energy to heat the materials during the mixing stage. Gandhi (2008) reported that the mixing of WMA ranged from 100 °C to 140 °C compared to the mixing temperatures of 150 °C to 180 °C for HMA. The technologies incorporated additive to be added into the mixes to reduce mixing temperature without affecting the mix performance (Aman, 2013). However, stripping occurred while production of a mixes at lower temperature.

According to Kim *et al*., (2012) found that asphalt mixture preparation using WMA additives suffered the increasing tendencies to rutting and moisture susceptibility. According to Aman (2013), Due to, the moisture incompletely dried from aggregates and possible presence of water in mixtures, which affected to aggregate-bitumen bonding due to be heated and dried at lower temperatures. Synthetic zeolites are metallic aluminosilicates, which contain approximately 20% water by weight in their microstructure (Prowell and Hurley 2007a).

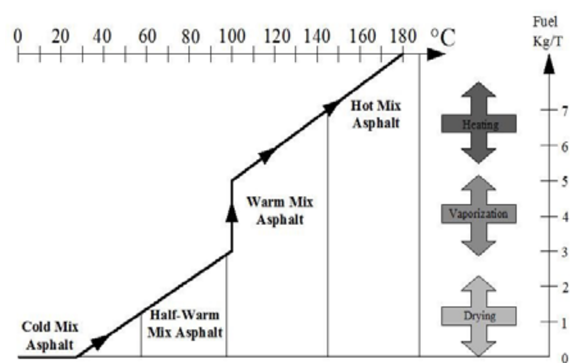

Figure-6. The classification of asphalt mix according to production temperature and fuel consumption.

The functionality of WMA technologies is valid on the reduction of asphalt binder viscosity in particular temperature. The lower asphalt binder viscosity lets achieve good coating of aggregates with binder in lower temperature than it is used for the hot mix asphalt. Commonly the hot mix asphalt mixes are produced in temperature from 140 °C to 180 °C and compacted in temperature from 160 °C iki 120 °C. The temperature of asphalt mix production has direct impact to the binder viscosity, at the same time and for the compaction. Then hot mix asphalt temperature is reduced, the binder viscosity increases and became more resistant to deformation. It causes worse compaction. Finally the

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binder becomes so hard that the compaction is impossible. Using hot mix asphalt technologies this temperature is around 79 °C.

Overview and advantages of foamed asphalt

Foamed asphalt or asphalt foam refers to asphalt that is "foamed" into the form of numerous bubbles. In the road paving industry as well as in Foam Asphalt 101, foamed asphalt used in pavement rehabilitation referred to as pavement recycling as a stabilization agent. The basic idea of asphalt foaming is to inject a small quantity of cold water (usually with a mass ratio of 1% to 5% to the asphalt binder) together with compressed air into hot asphalt (140 °C to 170 °C) in a specially designed chamber. The water experiences a sudden temperature increase and becomes steam. When the mixture of asphalt cement, steam and compressed air is injected into the ambient air, asphalt is temporarily expanded into numerous bubbles with greatly increased surface area per unit mass. The expanded asphalt is then introduced to either Reclaimed Asphalt Pavement (RAAP), RAP aggregate base or aggregate base to improve the material properties of material.

The purpose of asphalt foaming is to make it easier for asphalt to disperse into cold RAP and/or granular materials at ambient temperature. Liquid asphalt binder at high temperature without foaming would immediately become globules when it contacts cold aggregates and impossible to mix.Foamed asphalt, or asphalt bubbles can be dispersed into the mix fairly uniformly. An excellent analogue to this cold mixing process is to beat an egg white into foam, which can be mixed with dry flour (Raffaelli, 2004).

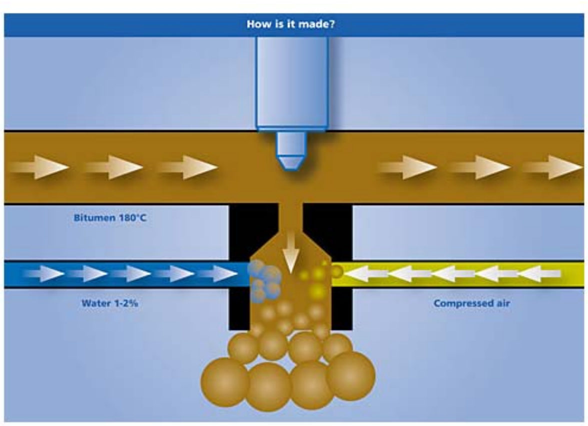

Figure-7. How the foaming process works.

Optimum foaming condition

Foamed bitumen is characterized in terms of ER Max and Half-Life. The ER Max is defined as the ratio between the maximum volume achieve in the foam state and the final volume of the binder measured once when the foam has dissipated. The half-life is the time, in seconds, between the moment the foam achieves its maximum volume and the time it dissipates to half of the maximum volume. ERMax and half-life can be optimized at the optimum foaming condition, and FA mixes will have good performance at this optimum condition (Nataatmadja, 2001). The optimum foaming conditions were determined by analyzing the test results obtained under different conditions.

Optimum moisture content

The moisture content during mixing and compaction is considered to be the most important criteria for mix design of foam asphalt mix. The amount of water added to mixture was approximately 70% of the OMC recommended by Wirtgen Co, 1998. OMCs of all groups will be tested in accordance with ASTM D 15573. The method based on Marshall Stability has been most commonly used for foam asphalt mix design. In order to determine the design bitumen content, five batches of specimens with five bitumen contents (from 1% to 5%, 1% apart) are prepare for each group by Marshall compactor under the OMC. In order to reflect the worst condition, specimens are soaked in the 25 ºC water bath for 24 h. Conditioned specimens are subjected to indirect tensile strength test. After ITS testing, a convex curve of the measured ITS versus bitumen content for all batches of each group were made. Through the curve, the bitumen content at which the soaked ITS was at its maximum was taken as the design bitumen content.

Table-1. Example of existing and potential warm mix technologies.

WMA Additives	WMA Technology	Company	Recommended Additive/ Usage
Foaming Additive	Aspha-min®	Eurovia and MHI	0.3% by total weight of mixture
	Advera WMA	PQ Corporation	0.25% by total weight of mixture
	WAM-Foam®	Kolo Veidekke Shell Bitument	No additive. It is a two component binder system that introduces a soft and hard foamed binder at different stages during plant production.
	LEA®	LEA-CO	3% water with fine sand mix with hot coarse aggregate
	LEAB®	Royal Bam Group	0.1% by weight of binder
	Double Barrel Green	Astec	2% by weight of binder

The advantages of foamed asphalt are well documented. One of it benefits is the foamed binder increases the shear strength and reduces the moisture susceptibility of granular materials. The strength characteristics of foamed asphalt approach those of cemented materials, but foamed asphalt is flexible and fatigue resistant.

Muthen (1998) in his report stated that foam treatment also can be used with a wider range of aggregate types than other cold mix processes. On the other hand, foamed asphalt also reduced binder and transportation costs, as foamed asphalt requires less binder and water than other types of cold mixing. Besides that, it saving in time, because foamed asphalt can be compacted immediately and can carry traffic almost immediately after compaction is completed.

In term of environment, foamed asphalt give energy conservation, because only the bitumen needs to be heated while the aggregates are mixed in while cold and damp (no need for drying). Environmental side-effects resulting from the evaporation of volatiles from the mix are avoided since curing does not result in the release of volatiles. Foamed asphalt also can be stockpiled with no risk of binder runoff or leeching. Since foamed asphalt remains workable for much extended periods, the usual time constraints for achieving compaction, shaping and finishing of the layer are avoided.

Foamed asphalt layers can be constructed in adverse weather conditions, such as in cold weather or light rain, without affecting the workability or the quality of the finished layer.

CONCLUSIONS

Based on the extensive literature review, the research that used foamed asphalt mixes are gaining in popularity owing to their good performance, ease of construction and compatibility with a wide range of aggregate types. In the first part the performance issues on environment and waste material are described. In the second part, RAP production and binder extraction of RAP are discussed. Description overview of Warm Mix Asphalt and foamed asphalt in terms of potential benefit and drawback are elaborate in order to interpret these findings with theoretical substantiation.

As with all bituminous mixes, it is essential to have a proper mix design procedure for foamed asphalt mixes in order to optimize the usage of available materials and to optimize mix properties. Fortunately, for foamed asphalt mixes, the mix design can be accomplished by relatively simple test procedures and by adhering to certain restrictions with respect to the materials used.

The implementation of WMA technology on asphalt pavement either for new construction or for maintenance of existing layer shall represent a new addition on additive or technology as compared to the conventional HMA which caused an additional cost as compared to HMA (Abdullah, 2014). Many new techniques are being developed to achieve foaming of the bitumen. However, since the mix design proposed herein concentrates on optimizing the mix properties, it would work equally well with all foam asphalt mixes, irrespective of the type of apparatus used to produce the foamed bitumen.

In conclusion, this paper described current practical experienced among researchers and industrial practitioners while implementing WMA technology including constituent materials, mix design and mechanical performance issues. Within this, the dosage recommendation for most of WMA additives and its benefits were clearly explained as essential for a better understanding of the application of WMA technology in pavement constructions.

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