

# An Overall Review: Modified Asphalt Binder Containing Sasobit in Warm-Mix Asphalt Technology

Mohd. Rosli Hainin<sup>a</sup>, Md. Maniruzzaman A. Aziz<sup>ab\*</sup>, Shahab Moeini Feizabadi<sup>a</sup>, Ramadhansyah Putra Jaya<sup>a</sup>, Norhidayah Abdul Hassan<sup>a</sup>, Fauzan Mohd Jakarni<sup>c</sup>

<sup>a</sup>Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor Malaysia

<sup>b</sup>UTM Construction Research Centre (CRC), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor Malaysia

<sup>c</sup>Department of Civil Engineering, Faculty of Engineering, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

\*Corresponding author: mzaman@utm.my

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## Graphical abstract



## Abstract

Increasing emission of greenhouse gases is an environmental issue, and it is a great concern to curb this problem from further harm to the environment. Warm-mix asphalt (WMA) is one of efforts to curb a reduction in the temperature at which asphalt mixes are produced. WMA can reduce the temperature to 100°C and even lower without compromising the performance of asphalt binder. WMA has various benefits such as, reduction of asphalt binder temperature, reduction in energy consumption and less air pollution. It reduces short-term aging, compacting effort and decreases temperature drop during transportation. Sasobit is one of the organic additives of warm mix asphalt. It is used as a binder modifier to produce rut resistant mixtures. It provides the option of reducing fume emissions, saving energy and reducing production cycles. Therefore, sasobit is the preferred additive for warm-mix asphalt (WMA). In addition, Complex shear modulus will be determined to find the rutting factor and fatigue factor for the asphalt binder ( $G^*/\sin\delta$  and  $G^*\sin\delta$  respectively). The overall purposes of this study are to determine the importance of using WMA as a green pavement and introducing sasobit for modifying virgin asphalt binder.

**Keywords:** WMA; sasobit; global warming; sustainable pavement; complex shear modulus( $G^*$ ); dielectric constant

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## 1.0 INTRODUCTION

Bitumen plays an important role in road construction as a typical binder. In this process, heating is required to handle bitumen due to its high viscosity. Besides, the physical and chemical properties of bitumen binder, it possess a unique and fundamental microwave properties (permittivity). It is a lowloss material as loss tangent less than 0.5 and its microwave permittivity value ranges from 2 to 7 depending on the grade of bitumen [1] Unfortunately, this fact involves some energy, environmental and health problems like fume emissions. Common asphalt classification by the production temperature is cold mix (0-30°C), half warm asphalt (65-100°C); warm mix asphalt (100-140°C) and hot mix asphalt (above 140°C) [2]. Reduction of temperature of warm-mix asphalt helps to global warming problem. According to Ten elements were listed as environmental impact factors [3]: global warming (increase in temperature due to greenhouse gases), acidification, eutrophication, Fossil Fuel Depletion, Water Intake, Criteria Air Pollutants, Human Health (noncancerous), Human Health

(cancerous), Smog Formation, Ozone Depletion, Ecological Toxicity, which warm-mix asphalt improved the environmental performance of HMA in all considered environmental categories. Furthermore, modern traffic with a large number of trucks and increased tire pressure, offers a serious challenge to the design, construction and maintenance of asphalt pavements through the world. EPU 2001 reported which maintaining cost of roads was RM 8.9 billion, RM 5.1 billion development of new road. The price of HMA increased from \$40 per ton in 2004 to \$120 per ton in 2007 [2]. In addition, each particular failure mechanism is a function of asphalt's basic intermolecular chemistry. Currently, not enough asphalt chemical knowledge to adequately predict performance, and until now, researchers are unable to know the chemical formula for asphalt binder. So, Physical and rheological properties of asphalt binder play an important role in investigating its properties. Figure 1 illustrates the flow chart of discussion in this review paper.

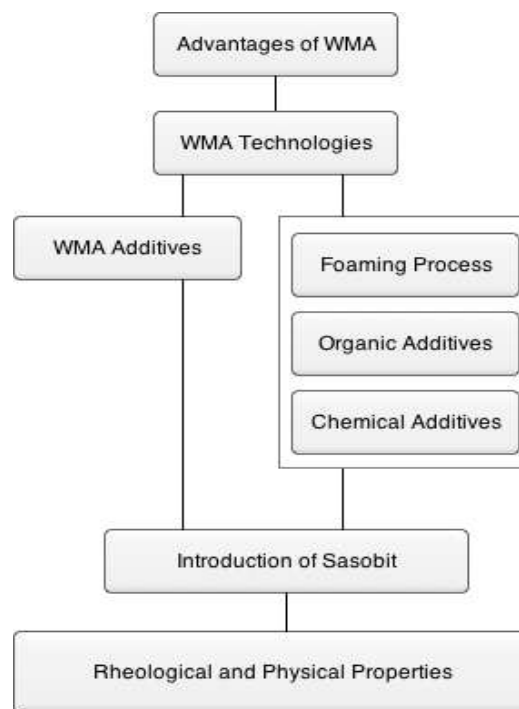


Figure 1 The flow chart of discussion in this review paper

## 2.0 ADVANTAGES OF WMA

### 2.1 Energy Consumption

An estimated amount of 48% of the total energy consumption occurs during mixing and drying aggregates [4]. This is why, one of the most important benefits of warm-mix asphalt is reduction in energy consumption required by burning fuels with reduction of asphalt binder temperature during production (during quarry mixing and paving compacting) [5].

### 2.2 Improving Air Quality

WMA can improve workability and emissions condition [6]. Reduction of emissions of hazardous air pollutants (HAP) from burning fuels at the plant, which considering that 30-50 percent of overhead costs at an asphalt plant can be attributed to emission control [5]. WMA reduces emissions of greenhouse gases (CO<sub>2</sub>) and traditional gaseous pollutants (CO, NO<sub>x</sub>, and SO<sub>2</sub>) [7].

In addition, WMA reduces fuel usage [8]: 11% saving for any 10°C reduction of temperature, 30-35% fuel savings and processes where a portion of the aggregates is not heated above the boiling point of water have shown savings of 34 to 47%. Generally, WMA in compare with HMA has 30% less energy, 30% less carbon dioxide (CO<sub>2</sub>) emission, 50-60% less dust emission [9].

### 2.3 Transportation

Aqua black solution reported decreasing temperature drop during transportation lead to extension of the paving season into cold weather. Furthermore, the extension of hauling distance is another advantage of WMA [3].

### 2.4 Using Higher Percentage of Reclaimed Asphalt Pavement (RAP)

Aqua black solution guideline, lower temperatures means

possibility of running higher percentage of RAP (10- 15%); Reduces veil, increasing heat penetration, increasing baghouse temperature [3]. Superheated virgin aggregate more likely to dry and Lower WMA temperatures reduce oxidation of virgin binder, which is good for RAP in terms of cracking and, aged RAP binder and helps offset softer virgin binder in terms of rutting.

### 2.5 Simplify Maintenance and extend equipment life

Based on Aqua black solution, Some WMA systems use 10 or more solenoids to control critical components and it helps to simplify maintenance and extension of equipment life.

## 3.0 WMA TECHNOLOGIES

### 3.1 WMA Processes

Generally three types of technologies were considered in Warm-Mix Asphalt industry: foaming process, addition of organic additives and addition of chemical additives [7, 9], however, sometimes types two and three were categorized in one group as non-foaming WMA technology [10]. All of the existing products use at least one of these technologies, but there may be combination of them as well [2].

#### 3.1.1 Foaming Process

This technology consists of a physical production process known as foamed asphalt or by adding foaming material like Aspha-min [10-12] by addition of small amounts of water into the hot binder or directly into the mixing chamber. High temperature of bitumen cause to evaporate and the steam is entrapped, which generates a large volume of foam. This temporarily increases the volume of the binder and reduces the viscosity [6]. This lubricating action keeps the mix workable at temperature range of 130°C to 140°C [9]. Foaming process subdivided into two types: water-containing technologies and water-based technologies. Aspha-min, WAM

foam, Low Emission Asphalt and Double Barrel Green are in this category.

### 3.1.2 Addition of Organic Additives

In this process, organic additives are mixed with asphalt binder, which melt at about 80-120°C and these chemically change the viscosity-temperature behavior of asphalt binder [6, 8]. The temperature at which the wax melts is in direct relation to the carbon chain (C45 or more) [7]. The mix remains workable at temperature as low as 90°C [9]. This process subdivided into three types: Fischer-Tropsch wax, fatty acid amide and Montan wax [6]. Sasobit is in this category.

### 3.1.3 Addition of Chemical Additives

Another method of WMA production involves a two-stage

process. In the first stage, a specially manufactured soft asphalt binder is used which covers the aggregate surface at 100-120°C. In the second stage, harder grade of asphalt binder is added in powder, foam or, emulsion form to these pre-coated aggregates. The final mixture can be compacted at temperature as low as 80-90°C [9]. Although chemical additives are more frequent in the USA, they have also been used in European countries such as France and Norway. The temperature reduction ranges from 15-30°C (REVIX) to 50-75°C [7]. Evotherm, REVIX, Cecabase RT, Rediset WMX and Interlow T are in this category.

### 3.2 WMA Additives

Currently many technologies actively are marketed and available in the world. Table 1 illustrates performance of some additives for generating WMA.

**Table 1** Additives of WMA Technologies [2, 7, 8, 10-17]

Additives	Developed By	Type of Process	Recommendation Rates of Additives	Potential Saving	Country where technology is used	Reduction Temperature (°C)
Sasobit	Sasol International (Sasol Wax)	Organic Additives	0.8-3% by weight of binder	Energy: 30% Environment: 20%	Germany as well as 20 other countries	20-30
Aspha-min	Eurovia and MHI	Foaming (W-C)	0.3% by total weight of the mix	Energy: 20% CO <sub>2</sub> , SO <sub>2</sub> , NO <sub>2</sub> 18-25%	USA, Germany, France, Worldwide	20-30
WAM-foam	Shell International and KoloVeidekke	Foaming (W-B)	2-5% water by mass of hard binder	Energy: 35% CO <sub>2</sub> : 30-40% VOC: 50-60%	Australia, Worldwide	100-120
Evotherm	Mead Westvaco Asphalt Innovations.	Chemical Additives	0.5% of mass of bitumen emulsion. Emulsion contains 70% of bitumen	CO <sub>2</sub> , SO <sub>2</sub> : 40-60% Nox: 60% GES: 60% Energy: 55%	USA, France, Worldwide	85-115
Low Emission Asphalt	Lea Co.	Foaming	3% water with fine sand		USA, France, Spain, Italy	Less than 100
Advera	PQ Corporation	Foaming (W-C)	0.25% by total weight of the mix	Nox: 30% COV :60% CO: 60%	USA, North America	10-30
REVIX	Mathy Tech & Eng. Services and Paragon Technical Services INC	Chemical Additives			USA	15-25
Terex	TEREX Road building					
Double Barrel Green	ASTEC	Foaming (W-B)	2% water by mass of bitumen, Anti-Stripping Agent		USA	116-135
Cecabase RT	CECA ARKEMA Group	Chemical Additives	0.2% to 0.4% by mixture weight		USA, France	30
Rediset WMX	AKZO NOBEL	Chemical Additives	2% by mass of binder	Energy: 20%	USA	15-25

Ultrafoam GX	GENCOR Industries INC	Foaming (W-B)	1-2 % by mass of bitumen		USA	
LT Asphalt	Nynas	Foaming (W-B)	0.5-1% by mass of bitumen	Energy: 50%	Netherland, Italy	90
LEAB	Royal Bam Group	Foaming (W-B)	0.1% of bitumen weight of coating and adhesion additives		Netherland	90
Asphaltan B	Romonta GmbH		2-4% by mass of bitumen		Germany	20-30
Licomont BS	Clariant	Organic Additives	3% by mass of bitumen		Germany	20-30
Interlow T	Interchimica	Chemical Additives	0.3-0.5% by mass of bitumen		Italy	120
RH	China	Polyethylen Wax-based	4% by mass of bitumen		China	30

W-C: Water-containing; W-B: Water-based

## 4.0 INTRODUCTION OF SASOBIT

### 4.1 Primary Information

Sasobit is an organic additive of warm-mix asphalt [16, 17]. It is also known as FT paraffin wax [18-20] and asphalt flow improver [5, 18, 19, 21]. Sasobit is produced by sasol wax company in South Africa [18-20, 22], and according to AASHTO standing committee on highways technical meeting [23], it produce in Germany too. It is derived from coal gasification process [13, 18, 20] or natural gas [16]. Based on guideline of Sasol wax, sasobit is safe, easy to handle and can be used in food-grade applications such as adhesives and therefore holds in no health hazards for workers. According to Sasol guideline, sasobitis existing in two

forms: Pastille form (4mm diameter) and prill form (1mm diameter). Moreover, it is available in 2, 5, 20 and 25kg bags and 600kg super sacks [13, 21].

### 4.2 Chemical Properties

Sasol wax reported sasobit is identical to paraffin waxes that are found in crude oil, except that it has a higher molecular weight. It is the chemical composition described as fine crystalline materials in long-chain hydrocarbons, produced by Fischer-Tropsch (F-T) synthesis. Long chain is made with 40-115 carbon atom [5, 13, 17, 18]. Table 2 shows some chemical and physical properties of sasobit additive.

**Table 2** Chemical and physical properties of sasobit [10, 22, 23]

Properties	Values and range
Ingredients	Solid saturated Hydrocarbons
Physical State	Pastilles and pills
Visual Color	Greyish-white to yellowish
Odor	No odor
Molecular weight	Approx. 1000
Specific gravity	0.9 (25C)
Ph values	Neutral
Flashpoint	258C (ASTM D92)
Congeaing Temperature	100°C (Specification: Min 100°C)
Bookfield viscosity at 135°C	12cP (Specification: 10-14cP)
Solubility in water	Insoluble

### 4.3 Significant Temperatures

Sasobit forms a homogeneous solution with the bitumen and produces a significant reduction in its viscosity [19]. Melting point of sasobit is around 100°C and it completely dissolved in bitumen at temperature higher than 115°C [5, 20, 266], however, some studies have reported some ranges for melting point of sasobit: around 85-115°C [27] and 75-115°C [24]. At temperature below 100°C, sasobit reportedly forms a crystalline lattice structure in the binder that is basis for the increased resistance to rutting at service temperatures and leads to the added stability [5, 13, 23]. On the other hand, at temperature above its melting point, sasobit acts as flow improver by reducing the viscosity of the asphalt enabling mixing and compacting temperatures to be

reduced by 18-84°C [19].

### 4.4 Ranges of Dosages

Various percentages of sasobit were used in past experiences (all percentages are by mass of the binder): 1.5% [10], 2% [17, 20, 23], 1-4% [5, 24], 1-3% [23, 26] and 2-4% [5, 29], however, recommended addition rate is from 0.8 to 3% by mass of the binder [14, 22]. It should be note that usage of sasobit more than 4% has harmful impact on the bitumen [5].

### 4.5 Processes of Modification

Sasobit pills can mix with bitumen directly in a laboratory mixer. Blending temperature is 125°C and time of blending is 1 hour [18,

26], however, in some studies different blending temperatures and blending time were used [5, 24]. Sasobit modified binders have higher complex modulus, lower creep compliance and phase angle [19].

### 5.0 RHEOLOGICAL AND PHYSICAL PROPERTIES OF SASOBIT MODIFIED ASPHALT BINDER

Most related recent studies surveyed effect of sasobit additive on asphalt binder through conventional tests (penetration test, softening point test and ductility test) and superpave methods (rotational viscosity (RV), bending beam rheometer (BBR) and dynamic shear rheometer (DSR)). Furthermore, Rolling Thin Shear Rheometer (RTFO) and Pressure Aging Vessel (PAV) were used for estimating short-term aging and long-term aging respectively [28].

Addition of sasobit on virgin bitumen reduce the construction temperatures (mixing and compaction temperatures) of asphalt binder and can result in the recovered asphalt bitumen to become as soft as or even softer than virgin bitumen [4, 26].

Sasobit reduces the penetration value at 25°C [26] and increase the value of softening point [27]. It increases the binder stiffness value at lower temperatures, which could lead to the increasing the resistance of binder against permanent deformation (rutting) and rate of resistance depends on the amount of the modified added to the virgin binder [26].

Viscosity is an important property of asphalt binder since it affects mixing, laying and compaction temperatures of HMA mixtures [29-32]. In terms of viscoelastic properties, sasobit has two different performance based on temperatures. It can decrease viscosity of asphalt binder at high service temperature (like 135°C), whereas it has the opposite effect in low temperatures (like 80°C) and increase viscosity of virgin bitumen [24, 26]. The

viscosity of the asphalt is preferred to be 0.2 Pa.s when mixing with aggregate in an asphalt plant [29]. Eq. 1 and 2 are recommended determining construction temperatures as a function of the viscoelastic properties of asphalt binder.

Two major reasons of aging are oxidation and volatilization of light oils [5, 24, 32-34]. The extend of aging is evaluated in terms of an Aging Index (AI), which is defined as ratio between a rheological property of an aged binder and the same rheological property of the unaged binder [24]. AI is presented in Eq. 3. Adding sasobit to virgin bitumen decrease the Aging Index. This is why, rutting factor ( $G^*/\sin\delta$ ) is increased in both original and RTFO-aged samples with increasing sasobit [5], however, in mix design of WMA, construction temperatures, aggregate, additive type and asphalt binder grade, as, well as interactions among these factors, can affect the rut depth [23].

$$\text{Mixing temperatures} = 325 \omega^{-0.0135} \quad (1)$$

$$\text{Compaction temperatures} = 300 \omega^{-0.012} \quad (2)$$

Where Temperatures are in Fahrenheit (°F) and  $\omega$  is the frequency in rad/s for a phase angle of 86°C.

$$AI = \frac{(\text{Rheological Property})_{\text{Aged-condition}}}{(\text{Rheological Property})_{\text{unaged-condition}}} \quad (3)$$

Evaluating AI is complicated, because various variables such as binder type, test temperature range and sasobit content are related to it. The complex shear modulus ( $G^*$ ) is one of the most important rheological characteristics of viscoelastic materials [24]. It can be obtained by DSR test [27]. In addition,  $G^*/\sin\delta$  and  $G^*\sin\delta$  are two important values to measuring rutting and fatigue respectively. According to Asphalt Institute specification (2007), Table 3 illustrates the performance graded asphalt binder DSR.

**Table 3** Performance Graded Asphalt Binder DSR

Material	Value	Specification	HMA distress of concern
Unaged binder	$G^*/\sin\delta$	$\geq 1.0$ kPa (0.145 psi)	To control rutting depression
RTFO residue	$G^*/\sin\delta$	$\geq 2.2$ kPa (0.319 psi)	To control rutting depression
PAV residue	$G^*\sin\delta$	$\leq 5000$ kPa (725.163 psi)	To control fatigue cracking

$G^*$ : Complex Shear Modulus;  $\delta$ : Phase Angle

Network crystalline structure formed in the sasobit-modified binder reduces temperatures sensitivity and increase the elasticity of the binder. This is why, sasobit increase complex shear modulus ( $G^*$ ) and decrease phase angle ( $\delta$ ) of the binder samples regardless of aging condition and binder type [24, 27, 28, 32]. In addition, the rate of sasobit must carefully select to avoid early surface distress, especially due to fatigue failure at intermediate temperatures [3]. Effect of sasobit on phase angle is significant. It means sasobit can change the properties of asphalt significantly when added in asphalt [27].

Failure temperature is the temperature of bitumen which, performance grade of asphalt binder go up into next grade. The grade determination feature of the DSR can use for determining the failure temperature and the failed temperature rises remarkably with adding sasobit to the binder [10, 19] were reported which, the performance grade of asphalts can be

expanded by addition of Sasobit with the upper temperature increased by up to 13.5°C and lower temperature increased by up

to 6.9°C for 3% Sasobit modified WMA.

### 6.0 CONCLUSION

Warm-mix asphalt is a new asphalt technology, which saves energy and cost. It reduces the temperature of asphalt binder during mixing and laying stages. So, WMA as a sustainable pavement is good for environment with a drop of global warming and decreasing emissions of greenhouse gases in the atmosphere. One of the best additives in WMA industry is sasobit. Sasobit reduces the viscosity of asphalt binder at high temperatures. In addition, sasobit increases complex shear modulus ( $G^*$ ) value and rutting resistance at intermediate temperatures. Moreover, in lower production temperatures improve thermal and fatigue cracking resistance with reducing the ageing of the bitumen during the production stages. Furthermore, sasobit has an upward trend in the performance grade of the virgin binder to the next grade with increasing the failure temperature of the binder.

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