Comparison of Performance between Hot and Warm Mix Asphalt as Related to Compaction Design

Siti Nur Naqibah Kamarudin¹, Mohd Rosli Hainin¹, Mohd Khairul Idham Mohd Satar¹ and Muhammad Naqiuddin bin Mohd Ward¹
¹Faculty of Civil Engineering, Department of geotechnics and Transportation, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia.

E-mail: mrosli@utm.my

Abstract. Hot mix asphalt (HMA) is a conventional mixture that is commonly used in Malaysia. Production of HMA requires high temperature which produces high carbon dioxide (CO²) emission and gives bad impact to the environment. During the construction, cool weather is one of the factor that can influence the temperature of HMA mixture. It will reduce the mixture temperature during compaction. Warm mix asphalt (WMA) is one of the methods to overcome this issue. Even though HMA mixture is produced at higher temperature, the rate of cooling also high. This study focused on evaluating the performance of HMA and WMA as related to the compaction design. The types of mixture used were HMA and WMA with 14 mm nominal maximum aggregate size. The oil based additive used in WMA was Cecabase. This study was conducted at Kg Ayer Merah, Mersing where real time temperature and density were measured during construction. Rate of cooling, degree of compaction (DOC) and rutting performance of mixtures were analysed. By comparing to HMA mixture, the results show that WMA mixture has lower rate of cooling where the temperature of WMA mixture decreases slowly but still provides higher density. WMA also has higher DOC which provides better workability of compaction compared to HMA mixture. Other than that, WMA mixture has lower resilient modulus than HMA mixture which could suggest that WMA mixture is more susceptible to rutting.

1. Introduction
Hot mix asphalt (HMA) is a conventional mixtures to construct asphalt pavements. However, nowadays all agencies are starting to acknowledge the importance of sustainability in road construction. Warm mix asphalt (WMA) is one of the strategies to achieve the sustainable construction. WMA technology could reduce carbon footprint and emissions by lowering the temperature during production and construction. WMA also has many other advantages compared to HMA such as lower cost, better performance and healthier environment [1].

In order to enhance the quality of newly laid flexible pavement, proper compaction is crucial. Appropriate temperature during compaction is very important to provide the strength of the pavement. The strength could be attained by increasing the pavement density to withstand the load of the vehicles and the weather. Reduced temperature during compaction will lessen the mixture workability thus caused an increment of voids in the pavement. The same prevails for the too high temperature where the
binder becomes less viscous and hindered the compaction. Therefore, measuring the cooling rate is one of the suitable methods to determine the ideal compaction of mixture. Instead of mixture temperature, there are other parameters that can influence the cooling rate of the asphalt mixture such as temperature of the existing layer, compaction process and weather. During construction, cool weather also one of the factor that will easily influence the HMA mixture where it will cause the reduction of temperature during compaction. Even though HMA have high temperature but it has high rate of cooling.

These factors affect compaction process for the pavement which is one of the most important part for road construction. Basically, low pavement density could also affects the strength and caused shorter life span and rutting. Therefore this study is very important to determine and compare the rate of cooling, the degree of compaction (DOC) and the rutting performance of HMA and WMA.

2. Literature Review

WMA is a technology that allow reduction in the temperature at which asphalt mixture is produced and placed [2]. It is produced by adding either zeolities, waxes, asphalt emulsions, or sometimes even water to the asphalt binder prior mixing. The production temperature of WMA is normally ranges from 100 to 140 °C [3]. Instead of supporting the sustainable development, WMA also improved field compaction, facilitate longer haul distances and cool weather pavement and healthier environment in term of reducing of fuel consumption and emissions. In addition, WMA has found to improve the performance in term of minimizing the thermal crack, block crack and oxidative hardening [4]. WMA also improves the aggregate coating as a result of lower asphalt binder viscosity [5-9].

Cecabase is one of the common additive used for WMA. It is a liquid chemical additive with the dosage of 0.2-0.5 % for all types of binders. Adding cecabase will not change the bitumen grade and no curing time required. Cecabase can be injected into the binder either at the mixing plant or at the asphalt terminal and relevant to be stored for a minimum one week at 160 °C. This additive improves the workability of bituminous mixtures. It can be produced and paved at lower temperature than standard HMA without any process modification or loss of mechanical properties [10].

2.1 Factors that influence performance of road construction

2.1.1 Temperature.

Previous study stated that the temperature of the asphalt mixture is important for better final quality performance [1]. Cooling rate is one of the suitable method to determine the optimum temperature of compaction by measuring the density after every roller passes. However, there are many factors influenced the cooling rate of the asphalt mixture which are the temperature of the underground, temperature of existing road, compaction process, compaction regimes, layer thickness and the weather during construction.

2.1.2 Compaction.

Compaction is the most important process during road construction with set of compactor rollers. It will affect the final quality layer because compaction is the last activity before the road is open for the public use [1]. Viscosity of the asphalt mixture is influenced by the different techniques for WMA, but on the other hand, the viscosity will increase again when the temperature of mixture is lower [11]. In order to obtain high density, optimum compaction should be reached.

2.2 Benefits of WMA

WMA is one of the potential technologies can be categorized in four groups according to the research literature overview which are environmental, production, paving and economic [12].
2.2.1 **Environmental.**
WMA is a technology that allows asphalt plant mixing to be produced at lower temperature [13]. It will reduce the emission of carbon dioxide by 30 %, dust emission by 50-60 % and greenhouse gasses by consuming less energy compared to HMA [1]. The workers also negatively be effected by exposure to the fumes which is produced when the reduction of emissions during asphalt paving process [6].

2.2.2 **Paving.**
If WMA mixes are produced at normal operating temperatures, it will allow longer haul distances and a longer construction season [14]. Lowering the paving temperature could reduce of oxidative hardening of the asphalt and improve the performance by minimizing thermal and block cracking. Low paving temperature also reduced the viscosity and improved working conditions for the workers, longer haul distances, reduced cooling rate and improve the workability [12].

2.2.3 **Economic.**
Less energy consumption significantly affect the cost. However, it also depends on the type of energy used during production process, the types of gaseous pollution and the maintenance cost of asphalt plant [6].

2.3 **Issues in WMA**
Rutting resistance performance is the major issue in WMA. Lowering the mix temperatures, in drying the aggregates and in the plant mixing, could potentially cause WMA to be more susceptible to moisture damage and rutting [14]. The in-service rutting potential of some WMA products can be increased because generally void content in WMA is lower than HMA as WMA have good workability in some products of WMA and together with a less oxidative hardening of the binder throughout the production process, despite that it can also conduct to an increased durability [15].

There are also some concern related to the production of WMA which increase the initial production cost and connected to the additional equipment needed for plants, allowing the use of specific technology or additives that bring some supplementary cost, which could be only partially compensated by lowering the operating temperature [15].

3. **Methodology**
This study involved several tests that have been conducted during construction and at laboratory work utilizing HMA and WMA with liquid chemical additive namely Cecabase. Asphalt binder type 80/100 was used. Table 1 shows the details of mixture design. During road construction, cooling rate method and density reading using PQI device test were conducted. After construction, coring was performed to obtain the compacted samples at one day, one month and four months.

| Type of premix | section | Description                          |
|---------------|---------|--------------------------------------|
| HMA (AC14)    | A       | A1 75 blows/ BC 5.33% / normal lay   |
|               |         | A2 75 blows/ BC 5.33% / double handling |
|               | B       | B1 50 blows/ BC 5.53% / normal lay   |
|               |         | B2 50 blows/ BC 5.53% / double handling |
|               | C       | C1 35 blows/ BC 5.83% / normal lay   |
|               |         | C2 35 blows/ BC 5.83% / double handling |
| WMA (AC14)    | D       | 75 blows/ BC 5.35% / normal lay      |
|               | E       | 50 blows/ BC 5.55% / double handling  |
|               | F       | 35 blows/ BC 5.85% / normal lay      |

**Table 1. Mixture Design**
4. Results and Discussion
Rate of cooling was conducted to determine optimum time available for compaction which obtained when the temperature of pavement decreases to 60 ° C. Based on the results, HMA has more rate of cooling compared to WMA. The ambient temperature, the temperature from old pavement, the compaction process and roller regimes and layer thickness can be influenced the cooling rate data. However, by taking an average, Table 2 shows that WMA premix achieves higher maximum density during compact compared to HMA premix. Concurrently, WMA has smaller slope graph of cooling rate than HMA. It can be summarized, temperature of WMA mixture decreases slowly but still provides higher density and keeps increasing. Different with HMA where the slope of graph is higher because of the temperature of HMA mixture decreases quickly but when the compaction is completed, the density achieved decreased. In nutshell, WMA mixture provide better cooling rate during compaction and provide higher density compared to HMA.

Table 2. Summary result for density during compact and slope graph.

| section | density during compact (kg/m³) | Slope graph of cooling rate |
|---------|--------------------------------|-----------------------------|
|         | initial | final | maximum |                      |
| A1      | 2080.5  | 2361.5| 2419.5  | 4.23                 |
| A2      | 2033.4  | 2144.8| 2163.4  | 0.59                 |
| B1      | 2068.2  | 2180.9| 2189.2  | 0.75                 |
| B2      | 2097.7  | 2180.7| 2188.4  | 0.40                 |
| C1      | 2136.3  | 2233.0| 2233.9  | 0.51                 |
| D       | 2101.9  | 2254.9| 2254.9  | 0.50                 |
| E       | 2238.9  | 2259.9| 2259.9  | 0.36                 |
| F       | 2198.0  | 2308.0| 2308.0  | 0.33                 |

Table 3 shows WMA premix has higher degree of compaction (DOC) than HMA and exceed minimum requirement of 98 % [16] except section F. Concisely, WMA has higher workability of compaction compared to HMA.

Table 3. DOC of pavement after 4 months.

| sample | SG coring | SG Marshall | DOC (%) |
|--------|-----------|-------------|---------|
| A1     | 2.1343    | 2.2102      | 96.57   |
| A2     | 2.1600    | 2.2102      | 97.73   |
| B1     | 2.0981    | 2.1772      | 96.37   |
| B2     | 2.1020    | 2.1772      | 96.55   |
| C1     | 2.0911    | 2.1763      | 96.09   |
| C2     | 2.0883    | 2.1763      | 95.96   |
| D      | 2.1551    | 2.176       | 99.04   |
| E      | 2.1294    | 2.1632      | 98.44   |
| F      | 2.0945    | 2.1595      | 96.99   |

Figure 1 plots the performance of coring samples after a month and 4 months. The performances were observed and compared. The graph demonstrate that after 4 months, the resilient modulus value is increasing from a month for both HMA and WMA. The resilient modulus was decreasing as compaction effort was decreased. High resilient modulus at 25 ° C shows that the mixture is more susceptible to fatigue crack. Mixture at Section A and mixture at Section D obtain the highest resilient modulus for
HMA and WMA respectively. In overall, this test concluded that HMA is more susceptible to fatigue cracking but less susceptible to rutting compared to WMA.

Figure 1. Performance of coring samples after a month and 4 months.

5. Conclusion
WMA technologies should be implemented because it is a good alternative and opportunity to improve road construction in Malaysia especially in its performance and environmental friendly. This is possible because WMA performs better in rate of cooling and DOC compared to HMA. WMA also has better workability in compaction and provides higher density even in low temperatures. Compaction is the most important process during road construction and it will affect the final quality layer because compaction is the last activity before the road is open for the public use. WMA also is more susceptible to rutting but less susceptible to fatigue cracking compared to HMA. These factors are the benefits of WMA. The implementation of WMA technology is uprising. Although it involves slight additional cost on the additive, the benefits on the engineering and environment are overwhelmed. More studies are suggested on mix design, long-term performance, cost benefits, and plant operations to further prove that the performance of WMA is truly as good or better than HMA [17].

6. Acknowledgement
Research work presented in this paper was supported by Universiti Teknologi Malaysia (grant number Q.J 130000.2522.15H16, Q.J 130000.2522.17H69, Q.J 130000.2522.11H35, Q.J 130000.2522.14J09). The financial assistance for this study is highly appreciated.

References
[1] Frank B, Seirgei M, and Andre D 2012. Warm Mix Asphalt - Too Cold to Handle? Learning to Deal with the Operational Consequences of Warm Mix Asphalt. 5th Eurasphalt & Eurobitume Congress, Istanbul
[2] D'Angelo J A, Harm E E, Bartoszek J C, Baumgardner G L, Corrigan M R, Cowsert J E, and Prowell B D 2008. Warm-mix asph.: European prac. (No. FHWA-PL-08-007)
[3] Das A 2004. Warm mix asphalt 3-4
[4] Hurley G C and Prowell B D 2005. Evaluation of Sasobit for use in warm mix asphalt. NCAT report, 5(06)

5
[5] Abdullah M E, Hainin M R, Yousof N I M, Zamhari K A and Hassan N 2016. Laboratory evaluation on the characteristics and pollutant emissions of nanoclay and chemical warm mix asphalt modified binders. Const. and Build. Mater. 113 488-497

[6] Abdullah M E, Ahmad Zamhari K, Buhari R, Abu Bakar S K, Kamaruddin M N H and Nayan N, Hainin M R, Hassan A N, Hassan S A, Yusoff M N I 2014. Warm mix asphalt technology: a review. J. Teknol. 71 39-52

[7] Aziz M M A, Hainin M R, Yaacob H, Feizabadi S M, Shokri M and Warid M M N 2014. Performance of warm-mix asphalt in the highway industry. Mater. Research Innov. 18 S6-245

[8] Abdullah M E, Zamhari K A, Hainin M R, Oluwasola E A, Yusoff N I M and Hassan N A 2016. High temperature characteristics of warm mix asphalt mixtures with nanoclay and chemical warm mix asphalt modified binders. J. of Cleaner Product. 122 326-334

[9] Abdullah M E, Zamhari K A, Hainin M R, Oluwasola E A, Hassan N A and Yusoff N I M 2016. Engineering properties of asphalt binders containing nanoclay and chemical warm-mix asphalt additives. Const. and Build. Mater. 112 232-240

[10] Oliviero Rossi C, Teltayev B, and Angelico R. 2017. Adhesion Promoters in Bituminous Road Materials: A Review. Appl. Sci. 7 524

[11] Brian D P, Graham C H and Bob F 2012. Warm-Mix Asphalt: Best Practice. National Asph. Pav. Assoc. (NAPA) 3rd Edition

[12] Martins Z 2010. Warm mix asph. investigation. Master of science thesis, Technical University of Denmark, Kgs. Lyngby, Denmark

[13] Timothy R, Greg J, and John G n.d. Dev. of Warm Mix Asph. Policies and Spec. in Minnesota. Minnesota: Minnesota Department of Transportation, Office of Materials and Road Research

[14] James T and James L 2010. Evaluating constructability and properties of warm mix asphalt. Georgia Ins. of Tech. (Atlanta), Final report

[15] Capitão S D, Picado-Santos L G and Martinho F 2012. Pavement engineering materials: Review on the use of warm-mix asphalt. Const. and Build. Mater. 36 1016-1024

[16] Jabatan Kerja Raya 2008. Standard Specification for Road Works, Section-4: Flexible Pavement. Kuala Lumpur: Jab. Kerja Raya Malaysia

[17] Rubio M C, Martinez G, Baena L and Moreno F 2012. Warm mix asphalt: an overview. J. of Cleaner Product. 24 76-84