Resilient modulus of Advera® warm mixture asphalt incorporating reclaimed asphalt pavement (RAP) materials

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Abstract. This paper presents the effects of using reclaimed asphalt pavements (RAP) materials in asphalt mixture as an alternative solution to overcome the cost of construction and rehabilitation works as well as assessing the resilient modulus characteristic of control and modified mixtures respectively. To achieve this aim, four series of mix portions with 4%, 5%, 6% and 7% Advera® were blended into asphalt binder. Then the modified binder were added into mixture with four series of the mixture replacement with 10%, 20%, 30% and 40% RAP. Resilient modulus test was performed at different mixing temperature (135°C and 125°C) and test temperature (25°C and 40°C) respectively. Consequently the quadratic model for resilient modulus was established. The optimum of Advera® content was found to be 5%. At 5% Advera content, the resilient modulus of the modified RAP mixture was significantly improved.

1. Introduction
Sustainability in context of the new asphalt industry can be explained through decreasing the energy consumption and emissions process at plant. It can be implemented through reducing of the mixing temperature in asphalt plant mixtures. The sustainable production processes significantly achieved with combination of recycled materials. In pavement industry, recycling can been referred as a process of production hot mix asphalt (HMA) by blending of waste milling materials such as reclaimed asphalt pavement (RAP) with new aggregate and bitumen or recycling agent. Reclaimed asphalt pavement (RAP) is obtained by pavement milling process or from a ripping and crushing operation [1]. Previous studies by Du [2] stated that sustainability in asphalt industry can be achieved through combination of reclaimed asphalt pavement (RAP) materials and warm mix asphalt (WMA). This sustainable alternative by recycling method resulting reduction in natural resources and energy. Recycling becomes one of popular rehabilitation technique based on field and laboratory data supported with continuous performance data. For that reason, several studies found that the factors influencing rehabilitation technique are economic consideration, energy conservation, environmental effects and engineering consideration.

In Malaysian perspective, various recycling techniques are adopted for rehabilitation work of flexible pavements. Malaysia’s roads network covers 144, 403 km with 116,169 km of pave road and 1,821 km is expressway [3]. Recently, the construction of Pan Borneo highway that approved under 2015 Malaysian Budget with total length 1,663 km. From that total length 936 km in Sarawak, 727 km in Sabah mostly mirror the existing trunk road, and it involves the widening of the present three-meter wide single-carriageway into a dual carriageway. Most of the paved roads in Malaysia are flexible pavement that consist typically of bituminous surfacing, granular road base, drainage sub base and the
formation subgrade. It can be said that, the deteriorated of wearing course disposed a large volumes in
the form of waste every 3 to 5 years [4].

Nowadays, the rapid development in new highway construction and networks has led to attract the
attention that focused on environmental impact issues. This issues arise in asphalt production plant with
increasing greenhouse gasses emissions. Conventional method used hot mix asphalt (HMA) to construct
road networks over the world. As a result many researcher suggested an alternative process in reducing
greenhouse gasses. The gasses emissions during production stage can be control by reducing fuel
consumption.

WMA has unlimited potential application and popular alternative compared to conventional hot-mix
asphalt (HMA). Through this WMA technologies, production temperature can be reduced around 25–
30°C. This reduction is due to chemical composition changes during the mixing process [5]. However some improvement and modification have to be made to enhance the characteristics and
strength of WMA. For this reason, many researchers have conducted numerous studies to establish new
additive materials that can be incorporated into mixture, mainly by introducing WMA additive into the
mixture.

RAP was opted as the aggregates replacement since it could be easily found in Malaysia. RAP, a
by-product from milling process of the pavements, is mostly disposed as pavements waste in road
rehabilitations. Its reutilization has the potential to create sustainable and productive materials. Another
reason that Advera® WMA additive had been chosen was because of its attested efficiency in reducing
asphalt productions temperature. Thus, this study was conducted to assess the effect of Advera WMA
additives on stiffness modulus characteristics of asphalt mixture incorporating RAP materials.

2. Materials and Methods
This section describes the materials and necessary method undertaken to achieve the objectives in this
study. The WMA additives material employed in this study was obtained from PQ Corporation
(Thailand).

2.1. Aggregate
The virgin aggregates selected in this study consisted of granite supplied by Hanson Quarry Sdn Bhd.
All aggregate properties complied the specification of the Malaysian Public Work Department [6]. The
specific gravity of the aggregate was used in determining specimen volumetric values (percent air void,
percent voids in mineral aggregate and percent void filled with asphalt). The granite aggregate exhibit
a specific gravity of 2.68 g/cm3 with water absorption and crushing value (ACV) were 0.81% and 27.8%
respectively. The aggregate gradation that used conformed to the Superpave mix design specification
[7-8]. Aggregates gradations selected for this study were from nominal maximum aggregate size
(NMAS) 12.5mm.

2.2. Asphalt Binder and Additive
In general, the asphalt binder consists around 5 to 7 percent of the total asphalt mixture that coating and
binding the aggregate particles together. Numerous study used additive or modifiers in order to enhance
and improve adhesion, elasticity and ability to flow at different temperatures. The conventional asphalt
binder that used in this study was PG64 supplied by Petronas, Malaysia. The relative density value of
PG64 binder was 1.03 according to the specification of the manufacturer. The details properties of binder
is shown in Table 1.
Table 1. Properties of asphalt binder used in this study

| Properties                             | JKR Specification / ASTM Requirement | Results |
|----------------------------------------|---------------------------------------|---------|
| Specific Gravity (g/cm³)               | Not stated                            | 1.221   |
| Softening Point (°C)                   | 45-52                                 | 49.6    |
| Penetration at 25°C (d mm)             | 80-100                                | 89.6    |
| Flash Point (COC), °C                  | 225 min                               | 262     |
| Ductility at 25 °C (cm)                | 100 min                               | 140     |
| Solubility in C₂HCL₃, %                | 99.5 max                              | 98.4    |
| Loss on Heating (RTFOT), %            | 0.5 max                               | 0.15    |

Advera® WMA additive is an aluminosilicate white powder purposely developed for warm mix asphalt application. It contains approximately 20% moisture which 100% passing 0.075 mm sieve. This synthetic material produced by PQ Corporation, United States. The optimal content of Advera® claimed by manufacturer is around 0.25% of the asphalt mix (4.8-5.0% by weight of the asphalt binder) able to reduce the asphalt binder production temperature by 20-30°C [9]. Arega [10] also stated that the presence of Advera® would never change the design of asphalt mixtures.

2.3. RAP Aggregates and Binders
The RAP material was collected along Yong Peng- Simpang Lima Road Paving, Batu Pahat district. The RAP used in this study was only the 12.5 mm passing material in order to produce a surface mixture. Evaluation of the binder properties were carried out on existing HMA such as an existing pavement or in a reclaimed asphalt pavement (RAP) stockpile. RAP binder need to extract from RAP materials to determine the bitumen content of the RAP. Procedure ASTM D 2172 [11] was used to obtain the value of the binder in the RAP. For the complete process to obtain bitumen content of the RAP, binder content of the RAP can be calculated based on the following equation:

\[
\text{Binder content, \%} = \frac{(w_1-w_2)-(w_2+w_3)}{w_1-w_2}
\]

In equation (1), \(w_1\) is the weight of the experimental, g; \(w_2\) and \(w_3\) are weight of water in the experimental materials, g and weight of mineral aggregate extraction, g respectively and \(w_4\) is the weight of mineral in the extract, g. From the test, the asphalt content of RAP was measured 5.74%.

2.4. Mixture Preparation and Laboratory Studies
The materials of this study were prepared with the present work used PG64 asphalt binder and Advera® as the binder base and warm mix asphalt additive material respectively. Five level of Advera® content were applied, namely, 0%, 4%, 5%, 6% and 7% by mass of the binder. The interval percentages of Advera® are reliable suggested by Oner and Sengoz [12] study which based on arithmetic average for representation of the corresponding group. Then the modified binder were added into mixture with five (5) series of the mixture replacement with 0, 10, 20, 30 and 40% RAP. Most testing methods and procedures strictly followed the standard method of American Society Testing Method (ASTM), British Standard (BS), and American Association of State Highway and Transportation Officials (AASHTO) and Malaysian Standard. An ordinary Portland cement (OPC) was used as filler and the aggregates were mixed into batches according to the designated gradation. The specimen size of 100mm diameter by 65 mm height requires approximately 1200 g of aggregate. Then, the aggregate was mixed using a 20L heavy-duty mixer. For enhance the bonding between the aggregate and binder, the aggregate were placed in the oven for 4 hours with temperature 135°C. Meanwhile, Advera® modified binder was preheated at the desired mixing temperature for 2 hours. The specimens were compacted in a mould using Superpave gyratory compactor with 100 gyrations.
2.5. Resilient Modulus Test

Resilient modulus (MR) is one of the basic and important parameter in determining the mechanical properties of asphalt mixture that can be used in the mechanistic design of pavement structure. Specimen preparation and testing procedure in this study was conducted based on ASTM D4123, Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixture using Universal Testing Machine [13](Figure 1). This indirect tension of resilient modulus test is non-destructive test where stress-strain measurement was used to evaluate the elastic properties of the mixes. This test was performed for both HMA and WMA mixtures. In order to obtain MR value, deformations for both horizontal and vertical was calculated on specimen at selected testing parameter. Based on ITS TM test, the stiffness modulus of the mixes MR, can be determined using following equation;

\[ M_R = \frac{P(\mu + 0.27)}{t\delta h} \]  

where in equation (2), \( P \) is the maximum dynamic load; \( \mu \) is Poisson’s ratio which for bituminous assumed to be 0.35; \( t \) is the specimen length, mm and \( \delta h \) is total horizontal recoverable deformation, mm. In this test, specimens were prepared and tested at 25 and 40°C test temperature. Selection of 25°C test temperature indicate that the mixture resistant to fatigue, whereas 40°C test temperature indicates the mixture resistant to rutting. Three (3) identical specimens (100 mm diameter with 63.5 ± 2.5 mm height) for each types of mixture were compacted at 4% ± 0.5% air void using Superpave™ Gyratory Compactor (SGC)

![Figure 1. Resilient Modulus Test using UTM.](image)

Prior to testing, the specimen was conditions for 4 hours and then tested at constant temperature 25°C and 40°C. Compressive load 1200N was applied vertically on cylindrical specimen and parallel to its vertical diametric plane with 100ms loading pulse width. Fig. 1 shows the process during testing by using UTM. The test sequence consists of fifty counts of condition pulses followed by five loading pulses. Pulse repetition period of 1000 ms was used to represent high traffic volume. Peak force and force pulse at the point 10% and 90% the rise time has been recorded. Parameter of modulus asphalt mixture from this test can be used in designing the pavement structure by applying theory of elastic layer. Therefore, prediction performance of the modified mixture can be done during design stage level.

3. Results and Discussion

3.1. Effect of Advera® on Asphalt Mixture

In this study, all specimens were conditioned and tested at temperatures of 25°C and 40°C to examine the effect of Advera® on asphalt mixture. The test was conducted at 25°C to indicate the mixture resistance to fatigue, while MR at 40°C indicate the mixture resistance to rutting. Figure 2 shows the graphical plot on the effect of Advera® contents against the MR for the virgin aggregate material at 25°C and 40°C test temperature. From Figure 2, a general trend indicating that the mixes prepared with high-percentage of Advera® gradually increase the MR value and slightly decrease after 6% of Advera® addition. The range of the resilient modulus, MR data were recorded in the range between 1243 Mpa to 2117 Mpa and 1153 Mpa to 1754 Mpa at 25°C and 40°C test temperature, respectively. This data clearly
shown that the resilient modulus value, $M_R$ of 40°C consistently lower than the specimen of temperature 25°C. This situation gives insight that the resilient modulus value, $M_R$ reduces by approximately 7% - 19% when the test temperature increase from 25°C to 40°C. Nevertheless, for the control virgin aggregate mixture, the range value of $M_R$ increased by 22% from 853 MPa to 1043 MPa by decreasing the test temperature. It can be observed that, virgin aggregate mixture with 5% Advera® experienced the highest $M_R$ compared to the control, which 2117 MPa and 1754 MPa, respectively. The increment of the $M_R$ around 165% and 101% compared to the control mixture at 25°C and 40°C were due to the presence of Advera® slightly affected the rutting resistance. At higher temperatures, decreases the stiffness, $G^*$ and increases the phase angle, $\delta$ for all modified samples resulting decreases in $M_R$ values.

The data did not show much difference in the mixture with 4% Advera® and 6% Advera®. These mixture exhibit slightly lower $M_R$, while a tiny increase in $M_R$ is shown in mixture with 7% Advera®. The previous study conducted by Sadeq [14] found that the increase content of Advera® increases the $M_R$ as the temperature affected on the resilient modulus value at the low tests temperature. The $M_R$ exhibit higher due to the susceptibility asphalt mixture. The finding show that incorporating 5% Advera® at temperature of both 25°C and 40°C has higher potential of the improving the flexibility of the pavement due to soften of asphalt binder that cause pavement strength improvement. Therefore, the specimens exhibiting high resilient modulus indicate less flexibility under loading, as agreed by Yaacob et.al [15].

![Graph](image_url)

**Figure 2.** Effect of Advera® percentage on Resilient Modulus of Asphalt mixture containing Virgin Aggregate.

### 3.2. Effect of Advera® on RAP Material

Figure 3 displayed the resilient modulus values of Advera® modified mixture produced by using different RAP and Advera content. The effect of the specimen’s mixing temperature corresponds to resilient modulus were examined at 135°C and 125°C. As a comparison, the control of HMA mixture were prepared and all specimens were tested at 25°C and 40°C. From the bar chart, overall trend shows that the presence of Advera® increases the resilient modulus values, $M_R$ with specimens mixed at 135°C exhibit highest resilient modulus values, $M_R$ followed by modified mixture mixed at 125°C and control. It is also observed that, similar of the highest $M_R$ are measured for the WMA mixtures fabricated with 5% Advera® followed by 6%, 7% and 4% of Advera® for both specimen mixed at 125°C and 135°C, respectively. In addition, increasing RAP content in mixture also influenced the resilient modulus values, $M_R$. This has clarified the increment of resilient modulus at 40% of RAP content with 5% of Advera® from 3970 MPa to 5180 MPa compared with the virgin aggregate specimen at 135°C mixing temperature. This increment of 30.4% $M_R$ can be related to the following aspect that there is friction between the RAP aggregate due to presence of the former asphalt binder.
However, the WMA mixtures produced at 125°C shows the lowest resilient modulus value. Comparison evaluation of the modulus values for the WMA mixture with various RAP content provide evidence of the positive effect on 5% Advera® demonstrates better stiffness resistance even mixed at lowest temperatures [16]. The results of this study are in agreement with previous literature regarding the stiffness stability of Advera® and RAP in mixtures [17]. The resilient modulus is the modulus is the modulus of elasticity when the asphalt sample is loaded within its elastic range, where the deformation is fully recoverable. Therefore, the samples exhibiting high resilient modulus indicate less flexibility under loading. According to Public Work Department (2008), minimum resilient modulus value of the mixture should be 2500 Mpa. The range found in this study was higher, which also explained that the Advera® mixture with RAP had toughness characteristic when mixed at lower temperature compared to the control. Furthermore, resilient modulus test was also conducted at 40°C to evaluate the stiffness of modified mixtures at higher temperature. Figure 4 demonstrates the relationship between resilient modulus values with different Advera® content tested at 40°C test temperature. From the result, it found a similar trend with 25°C that increases content of Advera® resulting in a rise of the resilient modulus value. The highest resilient modulus value was achieved in asphalt mixture with 5% Advera with replacement 40% RAP mixed at 135°C. It can be observed that, addition of Advera® into the mixture resulting M̅e values increases by an average of 18%. Compared to control mixture, it was found that by incorporating 5% Advera® with 40% RAP mixed at 125°C improved stiffness modulus approximately 20%.

Figure 3. Effect of Advera® and RAP on asphalt mixture at 25°C

Figure 4. Effect of Advera® and RAP on asphalt mixture at 40°C
Resilient modulus test result shows that the specimens produced at lower temperature with high percentage of RAP may cause better stiffness modulus considering the influence of temperature on the mixture. The effect of test temperature at 25°C was compared with 40°C corresponds to resilient modulus. Further analysis of the mean results was conducted by one way ANOVA purposely to examine the significant difference among modified mixture including control with assuming level of significance (α) as 0.05. The result from experimental test then was analyse through design and analysis of experiments (DOE) using response surface method. Prediction analysis of the resilient modulus behaviour was conducted with the aid of software Minitab 18 behavioural model to predict the behaviour of conventional and modified mixtures containing different percentages of Advera® and RAP as shown in Figure 5. As can be seen from this figure, the MR value tends to increase, considerably increase in Advera® and RAP content. Hence, maximum MR is obtained at 5% Advera® with 40% RAP replacement. It was observed that when the value of percentage Advera reaches its optimum value, it reduces the MR value of mixture due to better interlock from RAP. The contour plot effect of mixed temperature and Advera® on MR is shown in Figure 6. This Figure 6 displays that general trend of the MR value increases with increase of mixed temperature. However, the addition up to 5% Advera at 135°C mixed temperature reached highest MR and tend to decrease after optimal value achieved.

![Figure 5. Effect of RAP and Advera on MR](image1)

![Figure 6. Effect of Temperature and Advera on MR](image2)

The quadratic model results for resilient modulus in form of ANOVA was obtained after backward elimination process. Elimination of non-significant variable was carried out to examine the significance variables only. The value of $R^2$ and adjusted $R^2$ is over 89% and show that regression model provides an excellent explanation of the relationship between the independent variables (Advera®, RAP and Temperatures) and the response (MR). It was also shown that, the associated $p$-value obtained for the model is lower than 0.05 ($α =0.05$ or 95% confidence level) indicates that the analysis of the model is statistically significant. Furthermore, factor A (RAP), factor B (Advera®) and factor C (Temperature) was assigned and found interaction effect of factor A (RAP) with factor B (Advera), interaction effect of B (Advera®) and factor C (Temperature) have significant effect. The results proved that the Advera® and RAP added into the mixture enhances the stiffness modulus. The non-significant terms are eliminated by backward elimination process to fit the quadratic models of MR. After eliminating the non-significant terms, the final response equation for MR was given as follows:

In coded terms:

$$MR = -2954 - 45A + 2234B - 29.3C - 0.89A2 - 320B2 + 35.8AB + 8.5AC$$

(3)

In actual factors:

$$MR = -2954 - 45 \text{ RAP} + 2234 \text{ Advera} - 29.3 \text{ Temp} - 0.89 \text{ RAP2} - 320 \text{ Advera}2 + 35.8$$

$$\text{RAPAdvera} + 8.5\text{Advera Temp}$$

(4)
4. Conclusions
In this investigation, stiffness modulus properties of control and Advera modified asphalt mixture were evaluated using resilient modulus test. The specimens were prepared at different mixed temperature and tested at 25°C and 40°C. The results are summarized as follows:

- Addition of combination of Advera in binder and RAP materials showed to have great potential to be used as modifier and aggregates in warm mix asphalt mixtures.
- Stiffness modulus characteristics of Advera modifies asphalt mixture improved compared to the control mixtures, and the mixture modified by higher amount of RAP showed to have better resistance against rutting.
- The addition up to 5% Advera at 135°C mixed temperature reached highest MR and tend to decrease after optimal value achieved.
- All in all, this finding concluded that the specimens produced at lower temperature with high percentage of RAP may cause better stiffness modulus considering the influence of temperature on the mixture.

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