Effect of HDPE Based Wastes on the Performance of AC-WC Mixture with RAP as coarse aggregate substitute

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Abstract. One attempt to avoid early pavement damage is to enhance asphalt quality as an aggregate binder. The addition of polymeric materials is frequently used to improve asphalt quality, particularly asphalt rigidity. Increased rigidity will enhance pavement performance against rutting, bleeding, and swelling, particularly in summer with a relatively elevated temperature. This study uses High Density Polyethylene (HDPE) polymer waste as a modifier in a mixture of Asphalt Concrete-Wearing Course (AC-WC) which also utilizes RAP waste as a coarse aggregate substitute. The aim of this study is to analyse the effect of waste materials on the AC-WC performance. Analysis was carried out after the Marshall test to obtain the values of air void, Void in Mineral Aggregate (VMA), Void Filled with Asphalt (VFA) stability, flow and Marshall Quotient (MQ). Marshall samples prepared with dry method modified HDPE asphalt binder, given a limit on the specifications of the number of each specimen. The percentage of HDPE as asphalt mixture is 0%, 1.6%, 1.8%, 2.0%, 2.2%, and 2.4% asphalt weight. The optimum asphalt level (KAO) used is 5.25%. Marshall test shows that the addition of 1.6% of HDPE in the AC-WC mixture and RAP can increase mixture stability by 1.74% and flow by 3.69%.

1. Introduction
As the most commonly used pavement in the globe, flexible pavements face the challenge of raising traffic loads and weather conditions, resulting in a rapid rise in road deterioration [1]. The characteristics of bitumen and aggregates can be altered in order to scale down this phenomenon so that the pavement resistance can be improved [2–5]. Modified bitumen with improved binder characteristic generally offers greater pavement performance in term of stability and flexibility [6–7].

Research demonstrates that countless polymers were utilized to change asphalt binder characteristic [8–11], yet just a couple were acceptable because of poorer performance or inefficient cost [12]. One of common polymer used for modifying asphalt binder to alleviate the deformation of asphalt pavement due to heavy traffic loads is polyethylene [13]. Polyethylene has likewise been observed to be one of the best polymer added substances to asphalt binder [14–15]. The use of high-density polyethylene (HDPE) as an asphalt binder modifier in asphalt concrete mixtures increases the perpetual deformation of asphalt concrete mixtures [16], enhances rutting resistance, upgrades moisture susceptibility and reduces the potential cracking [17].
In order to maintain pavement life as well as its function, asphalt pavements need to be maintained and rehabilitated that end up with waste materials consist of a mixture of aggregates and aged asphalt binder that potentially harmful to the environment. Due to economic and environmental issues [18-19], the waste material can be reuse in the new Hot Mix Asphalt (HMA) construction and known as Reclaimed Asphalt Pavement [20]. Noferini et al. [21] noted that the increment of RAP content in the mixtures increases the softening point and elastic behaviour of bitumen.

The aim of this study is to analyse effect of waste materials on the HMA layer especially on the Asphalt Concrete-Wearing Course (AC-WC). For this purpose, HDPE wastes have been used as modifier and coarse aggregates was substituted with RAP.

2. Experimental Study

The bitumen used in the study is Pertamina Asphalt PEN 60/70. The materials used in this research are:

- FA (Fine Aggregate) with a size of 0-5mm.
- MA (Medium Aggregate) with a size of 5-10 mm.
- RAP (Reclaimed Asphalt Pavement) with a size of 10-15 mm as substitute of coarse aggregate
- Filler using Fly Ash (Type F)

To generate aggregate distribution in asphalt blend, aggregate grading curves were designed according to Indonesian Highway Construction Specifications 2010. Figure 1 demonstrates the limestone aggregate and RAP gradation curves and the gradation limit used in this research.

![Figure 1 Grading curves of aggregates and specification limits](image)

The optimum bitumen weight for the aggregates and bitumen used in the Marshall test study was determined at the beginning of the study. To this end, mixtures with limestone aggregates, RAP, and 60/70 penetration bitumen were prepared for five bitumen content (4.0%, 4.5%, 5.0%, 5.5%, 6%). The Marshall test was carried out in order to determine the optimum bitumen rate and as a result the value for optimum bitumen rate was 5.25%.

At the next step, modified bitumen mixture was prepared as follows:

- Mixture with modified bitumen by 0.0% HDPE (control specimen)
- Mixture with modified bitumen by 1.6% HDPE
- Mixture with modified bitumen by 1.8% HDPE
- Mixture with modified bitumen by 2.0% HDPE
- Mixture with modified bitumen by 2.2% HDPE
- Mixture with modified bitumen by 2.4% HDPE
Performance evaluation of modified bitumen (air void, VMA, VFA, stability, and flow) were determined by Marshall Test with sum total of 18 (3x6) samples.

3. Results and discussion

3.1. Air Void
The air void value shows the percentage value of the cavity in an asphalt mixture. Air void affects the durability where the greater the air void value shows the porous mixture. This process causes air and water to easily enter the pavement layer resulting in an increase in the oxidation process which can accelerate the aging process of asphalt. The results of the air void value are shown in Figure 2.

It can be noted that the AC-WC concrete asphalt layer and RAP with the addition of HDPE plastic have a higher air void in the range of HDPE levels of 1.6%, 1.8%, and 2.0%. After this level, the air void value decreases. This is due to the increasing amount of plastic used and the asphalt content in RAP, so that the plastic asphalt mixture will become thicker when heated. This causes the difficulty of the asphalt-plastic mixture into the cavity in the mixture so that the resulting air void value will be lower. A very small air void causes the waterproof layer and air not to enter the mixture. If the air void value is small and the bitumen content used is quite high, then the possibility of a large bleeding occurs. The test results show all air void values still meet the specified specification limit of 3.5 - 5%, except for HDPE levels of 2.4%

3.2. VMA
VMA is the volume of cavity between the aggregate particles of a compacted paved mixture. VMA or better known as the aggregate cavity is one of the important parameters in the design of asphalt mixture, because of its effect on the resistance of the asphalt mixture. VMA shows the amount of asphalt from the cavity filled with asphalt. The value of the VMA test results is shown in Figure 3.
From the results of the analysis, the increasing levels of HDPE plastic used in the mixture will give a lower VMA value, this indicates that increasing the plastic content will have an effect on the weight of the mixture which tends to increase in value and results in a decrease in VMA value. The required VMA value is 15% so that from the test results it shows that HPDE levels of 1.6%, 1.8%, 2.0% entered into the required specification.

3.3. VFA
The cavity in the mixture occurs due to the presence of residual space between the composite constituent granules. This cavity in dry conditions will be filled with air and in wet conditions will be filled with water. The VFA criteria aim to maintain the durability of paved mixes by giving sufficient limits. The results of the VFA values can be seen in Figure 4.
minimum value of VFA is in accordance with the existing specifications of 65%, so that the results of the tests obtained indicate that the VFA values meet the standards.

3.4. Stability
Stability value is used as a parameter to measure the resistance to plastic melting from an asphalt mixture or the ability of a mixture to withstand deformations that occur due to traffic loads. The stability value for each mixture can be seen in Figure 5.

![Figure 5 Stability value of modified specimens](image)

From the graph it can be seen that the addition of HPDE with a level of 1.6% made the control mixture (0% HDPE) experience an increase in stability value from initially 1256.64 kg to 1278.5 kg with a percentage increase of 1.74%. We can conclusively conclude that the use of RAP and HDPE can increase viscosity in the asphalt content, and increase the stability of the mixture at the maximum limit and eventually decrease again. This is most likely due to adhesion inclination since RAP is still containing asphalt and HDPE which have the same physical properties as bitumen when melted. In this study the maximum HDPE addition limit in the AC-WC mixture with a RAP was 1.6%. At that limit, the addition of HPDE will increase stability but if more than that it will reduce stability. However

3.5. Flow
Flow shows the deformation of the test object due to loading. The value of flow is influenced by several factors including gradations, asphalt levels, aggregate shapes and surfaces. This value can be read directly from the reading of the flow dial when carrying out Marshall test. Flow values are expressed in millimeters and shown in Figure 6.
From the Figure 4, it can be seen that the addition of HDPE plastic to the AC-WC mixture with RAP increases the flow value to the maximum limit of 2.4%. Thus, it can be concluded that the more HDPE used makes the mixture more plastic because the nature of HPDE which is similar to bitumen. The combination of asphalt melt and HPDE will make the aggregate more completely enveloped and an increase in the quantity of HDPE negatively impacts the mixture’s internal friction.

3.6. Marshall quotient

MQ is calculated as the ratio of stability to flow that is used as an indicator of stiffness. The higher the MQ value of a mixture, the more rigid the mixture is. A greater MQ value shows a stiffer composition and therefore assumes that the mixture is likely to be more resistant to permanent deformation [22]. However, the higher the stiffness also increases the risk of cracking. The results for MQ test can be seen in Figure 7.

From the figure above, it can be seen that the addition of HDPE to the AC-WC mixture with RAP tends to decrease the MQ value. The highest MQ value occurs in the mixture with HDPE plastic content of 1.6%, which is equal to 380.21 kg / mm.
4. Conclusions
In this study, the HDPE based waste materials were added as modifier to the control specimen (AC-WC and RAP mixture while RAP was used as substitute to coarse aggregate). The positive effect of the HDPE can only be seen at 1.6% addition since the mixture with 1.6% HDPE obtained better Marshall Characteristics compared to control mixture without HDPE where stability increase of 1.74% and flow values increased by 3.69%.

References
[1] EU Transport in Figures-Statistical Pocketbook 2013, Publications Office of the European Union, 2013
[2] Tayabji S., Smith K.D., Van Dam T., Advanced High-Performance Materials for Highway Applications: A Report on the State of Technology, FHWA Report, Report no: FHWA-HIF-10-002; 2010.
[3] M. Garcia-Morales, P. Partal, E.J. Navarro, C. Gallegos, Effect of waste polymer addition on the rheology of modified bitumen Fuel, 85 (2006), pp. 936-943
[4] M. Naskar, T.K. Chaki, K.S. Reddy, Effect of waste plastic as modifier on thermal stability and degradation kinetics of bitumen/waste plastics blend” Thermochimica Acta, 509 (2010), pp. 128-134
[5] Changqing Fang, Jingbo Hu, Shisheng Zhou, Hongtao Wang, Maorong Zhang, Ying Zhang, Comparative Study of Asphalts Modified by Packaging Waste EPS and Waste PE, Polymer-Plastics Technology and Engineering, 50 (2011), pp. 220-224
[6] Wang, J. Yuan, K.W. Kim, F. Xiao, Chemical, thermal and rheological characteristics of composite polymerized asphalts, Fuel 227 (2018) 289–299
[7] Pedro Lastra-González, Miguel A. Calzada-Pére, Daniel Castro-Fresco, Ángel Vega-Zamanillo, Irene Indacoechea-Vega, “Comparative analysis of the performance of asphalt concretes modified by dry way with polymeric waste”, Construction and Building Materials 112 (2016) 1133-1140
[8] L.M.B. Costa, H.M.R.D. Silva, J.R.M. Oliveiran, S.R.M. Fernandes Incorporation of Waste Plastic in Asphalt Binders to Improve their Performance in the Pavement International Journal of Pavement Research and Technology, 6 (4) (2013), pp. 457-464
[9] C. Fang, J. Hun, S. Zhou, H. Wang, M. Zhang, Y. Zhang, Comparative study of asphalts modified by packaging waste EPS and waste PE Polymer-Plastics Technology and Engineering, 50 (2011), pp. 220-224
[10] S.E. Zoorob, L.B. Suparma, Laboratory design and investigation of the properties of continuously graded asphalitic concrete containing recycled plastics aggregate replacement (plastiphalt), Cement and Concrete Composites (2000 Aug.) 233.
[11] P. Jew, R.T. Woodhams, Polyethylene modified bitumens for paving applications, Proceedings of the Association of Asphalt Paving Technologies 55 (1982) 541.
[12] S.G. Jahromi, A. Khodaii, Effects of nanoclay on rheological properties of bitumen binder, Constr. Build. Mater. 23 (8) (2009) 2894–2904.
[13] H.A. Gibreil, C.P. Feng, Effects of high-density polyethylene and crumb rubber powder as modifiers on properties of hot mix asphalt, Constr. Build. Mater. 142 (2017) 101–108.
[14] R.T. Woodhams, Bitumen-polyolefin compositions, PCT Int. Appl. (1987 Sept.) (WO 87/5313 Al).
[15] N. Kuloglu, Effect of astragalus on characteristics of asphalt concrete, Journal of Materials in Civil Engineering 11 (4) (1999) 283.

[16] S. Hinislioglu, H.N. Aras, O.U. Bayrak, Effects of high density polyethylene on the permanent deformation of asphalt concrete, Indian J. Eng. Mater. Sci. (2005) 456–460.

[17] M. Attaelmanan, C.P. Feng, A.I. Al-Hadidy, Laboratory evaluation of HMA with high density polyethylene as a modifier, Constr. Build. Mater. 25 (5) (2011) 2764–2770.

[18] B. Huang, W. Kingery and A. Zhang, Laboratory study of fatigue characteristics of HMA mixtures containing RAP, in: International symposium on long performing asphalt pavements, Auburn, 2004.

[19] A. Copeland, “Reclaimed asphalt pavement in asphalt mixtures: state of the practice, FHWA-HRT-11-021”, 2011.

[20] Al-Qadi IL, Elseifi M and Carpenter SH (2007), Reclaimed Asphalt Pavement- A Literature Review, Research Report Fhwa-Ict-07-001, Illinois Center for Transportation.

[21] Noferini L, Simone A, Sangiorgi C and Mazzotta F 2017 Investigation on performances of asphalt mixtures made with Reclaimed Asphalt Pavement: Effects of interaction between virgin and RAP bitumen Int. J. Pavement Res. Technol. 10 322-32

[22] Hot Mix Asphalt Materials, Mixture Design and Construction, National Center for Asphalt Technology, 1991, p. 225.