Utilization of plastic waste with mix plastic softening aggregate method as performance of stability and quality asphalt concrete

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Abstract. To increase sidewalks in Indonesia there are several things that must be considered, such as aggregate quality, implementation methods and asphalt quality. The amount of waste plastic waste in Indonesia at this time and in the years to come, can be reprocessed, one of them is by using it as an additive in the technique of making asphalt concrete. It is expected that a complex problem related to the amount of plastic waste piles can be turned into an opportunity to build the acceleration and quality of concrete asphalt roads in Indonesia. The method used for this research is the wet process, which is the direct method of mixing plastic material into asphalt which is heated at temperature according to Tait's parameters, then added aggregate. The optimum asphalt used in this study was 5.7%. The variables used are 5%, 7%, and 9% of the plastic for substitution at the optimum level of asphalt used. Plastic variable added 100% high density polyethylene (HDPE) plastic, 100% polypropylene (PP), HDPE: PP and mixture (50:50), then Marshall Test. The best results were obtained by adding 9% plastic mixture variable with HDPE: PP ratio (1:1) resulting in an increase of 179% MQ then normal asphalt.

1. Introduction
The higher production of plastic waste generated will cause the necessity of processing of plastic waste. Based on data from the Ministry of Environment in 2012, the amount of garbage piling up in Indonesia has reached 175,000 ton / day or equal to 64 million tons / year. This issue needs to be handled seriously; the government has been reviewing many national solutions and strategies for handling plastic waste. People in general often burn plastic waste to reduce the amount of plastic waste in the environment when burned plastic waste will produce hydrogen sulphide gas (H2S) that can release toxic to the environment. One of the most dominant plastic waste is HDPE (High Density Polyethylene) plastic type, because this plastic has a nature that tend to be harder and resistant to high temperature or around 120 °C [1]. Plastic waste can also be converted into gas and naphtha fractions [2]. Various waste materials, plastic waste and municipal waste are of great concern in its management, among others, by finding ways to properly process plastic waste [3]. The process of removing plastic waste used by consumers, for example incineration or soil, is not fully accepted according to international standards. On the other hand, road traffic is increasing. Traffic intensity increases. Carrying capacity of road loads must be increased. The use of PCA (Plastic Coated Asphalt) for asphalt pavement helps for the reuse of plastics...
waste and for the improvement of road strength. This is a new innovative technique developed by the author. Plastics, a versatile packing material and a close to common man, become a problem to the environment after its use. Most used materials are bags, cups, films and foams, made up of PE, PP or PS [4].

According to the Director of Coastal and Marine Control and Damage Control of the Ministry of Environment and Forestry, until the end of 2016, Indonesia recorded as the second largest plastic waste contributor in the world. Every year Indonesia contributes 3.2 million tons of plastic waste annually. While China, the world's largest plastic waste contributor, produces 8.8 million tons of plastic waste per year.

The large amount of plastic waste in Indonesia today and in the coming years, can be recycled one of them by utilizing it to be an additive on the technique of making concrete asphalt. Plastics have the same carbon chain derivative characteristics as the asphalt but have different properties so as to have a positive impact on asphalt. It is expected that from a complex problem related to the amount of plastic waste pile can be transformed into an opportunity to build the acceleration and quality of asphalt concrete roads in Indonesia. In this study, additive materials added to asphalt concrete will come from two plastic variables i.e HDPE (High Density Polyethylene) and PP (Polypropylene). From the two variables will be done the process of grinding and mixed then identified the positive characteristics properties that produced on mixing of asphalt concrete, where if founded the most similar characteristics with asphalt and has a large advantage character then this research is expected will be used as an additive on the manufacture of asphalt concrete. Furthermore, the results of this research are concrete asphalt mixed with plastics will be tested its quality in the form of density test, stability, flow and Marshall Quotient (MQ) in laboratory.

2. Methodology

This research will be conducted at Industrial Waste Processing Laboratory, Chemical Engineering Department, Industrial Technology Faculty and Road Material Laboratory, Civil Infrastructure Engineering Department, Vocational Engineering Faculty, Institut Teknologi Sepuluh Nopember Surabaya from June to February 2018. This method used wet process to reduce the amount of asphalt by replacing it with plastic. Type of plastic used is Polypropylene (PP), and High Density Polyethylene (HDPE).

Polypropylene (PP) is a thermoplastic type polymer with properties between LDPE plastic and HDPE made from a combination of propylene monomers. Polypropylene (PP) In some parts for packaging, food packaging, textile materials, laboratory equipment, loudspeakers, automotive components, book binders and clothes hangers [5, 6].

HDPE is a thermoplastic material formed from carbon and hydrogen atoms that unite and form high molecular weight products. Then, with the application of heat and pressure, polyethylene is formed [5, 6].

2.1. Mix plastics with bitumen used wet process

To improve the quality of asphalt pavement, stone aggregates are used with specific characteristics based on SNI standard and AASHTO. Bitumen was mixed with waste plastic material by the following process. The waste plastics shredded to the required size of 2.5 mm – 5 mm. The bitumen is heated to 170 °C and aggregate also heated to 210 °C. The shredded waste plastic was sprayed over the hot bitumen (wet process) then plastics got softened and mixed dissolved with bitumen. After that, the aggregate should be fast mixed completely with it. The hot plastics coated aggregates was compacted into a block using compacting machine operated hydraulically and cooled. Then the block was subjected to a compressive test using universal testing machine [4].

2.2. Determine optimum asphalt content

Determination of Optimum Asphalt Content (OAC) is one of the first steps to find out how the best amount of asphalt can be added. The determination of OAC can be estimated theoretically by calculation, and then the result is made a range of values adding the asphalt. The materials used for
asphalt concrete mixture in this study consisted of 60/70 AC-WC, coarse aggregate, medium aggregate, fine aggregate and cement as filler.

2.3. Calculation range of Tait parameter

Determination of the melting temperature range of plastics, carried out by calculation approach of density and plastic viscosity at temperature above melting point and atmospheric pressure. The Tait equation is used to determine plastics density range.

\[ V_{\text{Volume Molar}}(V(P, T)) = V(0, T) \left\{ 1 + \frac{P}{B(T)} \right\} \]

Where:
- \( C \) is the common polymer constant (0.0894),
- \( V(0, T) \) is the isotherm condition with no pressure (cm³/g),
- \( B(T) \) is virial coefficient (bar),
- \( T \) is temperature (°C),

Then from equation 1, we determine the value of density by equation 2

\[ \text{Density} (P) = \frac{1}{V(P,T)} \]

The variables used were 5%, 7%, and 9% (wt. %) of plastic in the substitution on the value of the optimum levels of the asphalt which is used, with 100% High Density Polyethylene (HDPE) plastic, 100% Polypropylene (PP), HDPE: PP and mixtures (50:50), then conducted Marshall test. From the results of tests performed include stability, Flow, void in the mixed (VIM), void filled with asphalt (VFA), VMA (Voids in Mineral Aggregate), up to the value of the Marshall Quoetion (MQ) [7].

From the calculation results will be a reference in determining the value of plastic viscosity. The range of values of plastic viscosity at high temperatures and atmospheric pressure can be known through comparison of plastic density data with comparative density data in this case kerosene, as explained. But to find the flow time of plastic at high temperatures is very difficult, because of the limitations of the tool. From the viscosity equation, it is known that the viscosity is directly proportional to the density, it can be estimated that of all types of plastic to be used, the more temperature increases the lower the viscosity value, seen from the density value which also decreases with increasing temperature. Of the three types of plastic used plastic with the lowest viscosity is PP. These two physical properties may affect the physical properties of concrete asphalt, which will affect one of the tests carried out.

3. Results and Discussion

3.1. Result of Planning of Combined Aggregate Proportion

Mixed planning using the method established by [8] begins with the effective bitumen content that remains in accordance with the provisions. The available aggregate mixing is made into several variations to fulfill the requirements based on Marshall Parameters. In this study used merging 4 aggregate fractions by analytical way that is determination of composition based on trial and error. The aggregate proportion, including coarse aggregate, medium aggregate, fine aggregate, and filler. The following table 1 about combined aggregate proportion fraction [8].

\[ P = aA + bB + cC + dD \]

Where:
- \( P \) = Per cent pass the desired size (mm) filter,
- \( A \) = Per cent pass filter coarse aggregate fraction size d (mm),
- \( B \) = Per cent pass filter medium aggregate size d (mm),
- \( C \) = Per cent passes through the fine aggregate fraction filter size d (mm),
- \( D \) = Per cent pass through filter filler aggregate fraction size d (mm)

For percentage values of a, b, c obtained from graphical calculations in accordance with the specifications set forth in the Bina Marga (2010) regulation concerning aggregate limits of AC WC mixtures. The following Table 1 is concerning the percentage of aggregate aggregation.
The results obtained based on the combined aggregate calculation in table 1 that the aggregate boundary fits within the AC-WC specification with a 12% percentage for rough aggregates, 48% of medium aggregate, 38% fine aggregate, and 2% Filler.

Table 1. Combined aggregate 4 fractions

| No | Size   | % pass | % pass | % pass | % pass | % pass | % pass | 2   | Specification |
|----|--------|--------|--------|--------|--------|--------|--------|-----|--------------|
| 10 | 3/4"   | 0.00   | 0      | 100.00 | 12.00  | 100.00 | 38.00  | 100 | AC-WC        |
| 9  | 1/2"   | 0.00   | 0      | 28.57  | 3.42   | 99.58  | 47.79  | 100 |              |
| 8  | 3/8"   | 0.00   | 0      | 10.18  | 1.22   | 98.28  | 47.17  | 100 |              |
| 7  | No.4   | 0.00   | 0      | 7.65   | 0.91   | 47.59  | 22.84  | 100 |              |
| 6  | No.8   | 0.00   | 0      | 0.00   | 0.00   | 8.67   | 4.16   | 100 |              |
| 5  | No.16  | 0.00   | 0      | 0.00   | 0.00   | 6.76   | 3.25   | 100 |              |
| 4  | No.30  | 0.00   | 0      | 0.00   | 0.00   | 6.52   | 3.13   | 100 |              |
| 3  | No.50  | 0.00   | 0      | 0.00   | 0.00   | 0.00   | 21.60  | 100 |              |
| 2  | No.100 | 0.00   | 0      | 0.00   | 0.00   | 0.00   | 11.12  | 100 |              |
| 1  | No.200 | 0.00   | 0      | 0.00   | 0.00   | 0.00   | 7.75   | 100 |              |

3.2. Determination of Optimum / Theoretical Asphalt Level

To determine the level of asphalt which will be used as a basic plan, the calculation of the amount of proportion for each asphalt sample test material is first carried out. Such as asphalt weight and aggregate type with a total weight of 1200 grams for each sample. The determination of optimum asphalt content must fulfill the asphalt characteristic value according to the general specification requirements of Bina Marga in 2010.

\[
Pb = 0.035 \times (\%CA) + 0.045 \times (\%FA) + 0.18(\%)+ \text{ constants} \tag{4}
\]

Where; \( Pb \) = Optimum Asphalt Level (%), \( CA, FA, FF \) = the fraction of coarse, medium and fine aggregates (%)

From the calculation results it was found that the theoretical asphalt content was 5.7%, so we tried to see the actual optimum levels by making a range of 1% below and above 5.7%, namely 4.7%, 5.2%, 5.7%, 6.2% and 6.7%. Then the Marshall test was carried out, to find out the best mix.

Marshall Test on hot asphalt concrete mixture is stability, VMA (voids in mineral aggregate), VFA (voids filled with asphalt), VIM (voids in the mixture), flow (Mars) and Marshall Quotient (MQ) on the test specimen of each bitumen contents of one object. Table 2 Data Test Results Marshall Parameters [8].

Table 2. Data test results marshall parameters

| Marshall Parameter | Specification | Asphalt Level (%) |
|-------------------|---------------|-------------------|
|                   |               | 4.7   | 5.2   | 5.7   | 6.2   | 6.7   |
| Stabilisation     | >1000 Kg      | 1316  | 1356  | 1593  | 1524  | 1731  |
| Flow              | > 3 mm        | 3.80  | 4.25  | 4.32  | 4.30  | 4.10  |
| VIM               | 3.0% - 5.5%   | 2.70  | 3.01  | 3.17  | 2.78  | 2.31  |
| VFA               | > 65%         | 79.82 | 79.46 | 79.98 | 83.16 | 86.50 |
| VMA               | > 15%         | 13.31 | 14.64 | 15.81 | 16.50 | 17.10 |
| MQ                | >300 kg/mm    | 346.3 | 319.4 | 364.7 | 354.3 | 422.3 |
Of these, the optimum bitumen content that we can use is 5.7% because it reaches all parameters of Marshall Test. The addition of 5.7% asphalt will be a reference for the mixed composition plastic substitution. Total quantity of the asphalt sample used is 1200 grams, with a composition of 38% fine aggregate, 48% of medium aggregate, 12% coarse aggregate, 2% filler and 5.7% bitumen. The weight calculation of the asphalt added in each sample was 68.40 grams, thus it can be calculated the amount of addition of plastic (gram) substituted to asphalt for variables 5%, 7%, and 9% plastic addition.

Table 3. Test results marshall parameters

| Marshall Parameter | Specification       | Range       | Optimum Asphalt Level (OAL %) |
|--------------------|---------------------|-------------|-------------------------------|
| Stabilitation      | >1000 Kg            | 4.7 – 6.7   |                               |
| FLOW               | > 3 mm              | 4.7 – 6.7   |                               |
| VIM                | 3.0 - 5.5%          | 4.7 – 6.7   |                               |
| VMF                | > 65%               | 4.7 – 6.7   |                               |
| VMA                | > 15%               | 5.2 – 6.7   |                               |
| MQ                 | >250 kg/mm          | 4.7 – 6.2   |                               |
| Asphalt Level Plan (weight%) |               | 4. 5. 5. 6. 6. 7 |                          |

Table 4. Number of plastic substitutes against asphalt weight (grams)

| Levels of Plastic Substitution (%) | Plastic weight (gram) | Asphalt Weight (gram) | Total (gram) |
|-----------------------------------|-----------------------|-----------------------|--------------|
| 5                                 | 3.420                 | 64.980                | 68.40        |
| 7                                 | 4.788                 | 63.612                | 68.40        |
| 9                                 | 6.156                 | 62.244                | 68.40        |

3.3. Marshall Parameter Test Results Plastic Mixing Compared with Asphalt

Wherever As described previously, the asphalt has a standard specification following the general standard provisions of the Bina Marga 2010. The result of the concrete asphalt with the addition of plastic is then tested with Marshall Parameters and it is obtained with mixed characteristics, namely the value, of stability, flow, VIM, VFA, VMA and Marshall Quotient. Marshall Quotient (MQ) value is a mixture of stiffness properties. If the MQ value is too high, the mixture will tend to be too stiff and easy to crack. Conversely, if the MQ value is too low, the pavement becomes too flexible and tends to be less stable. The MQ value is obtained from the ratio between the stability value and the (melt) flow. The value of MQ will be greater if the stability value gets bigger and the value of the flow gets smaller.

Marshall Parameter tests have been carried out at Road Material Laboratory of Department of Infrastructure of Civil Engineering ITS Surabaya. Marshall Parameter test results can be seen in table 5. The test results show the MQ values were qualified by MQ specification for all plastic mixtures with additive except for variable with addition of 5% HDPE PP mixture and 7% HDPE PP mixture, i.e. more than 300 kg / mm. The value of Marshall Quotient (MQ) on the asphalt test results with the addition of HDPE plastics 5%, 7% and 9% respectively MQ value experienced an increasing trend of 316.80 kg / mm, 326.25 kg / mm, and 556.10 kg / mm. In the mixing of asphalt with the addition of PP plastic 5%, 7% and 9% are also successively MQ value has an upward trend of 444.88 kg / mm, 412 kg / mm, 570
kg / mm although at concentration 7% MQ. In mixing the asphalt with the addition of mixture of HDPE and PP plastic 5%, 7% and 9% also the MQ value has an increasing the trend of 204.37 kg / mm, 234.47 kg / mm, 652.16 kg / mm.

From the results of calculations by comparing the results of asphalt MQ values that use additional plastic with 100% pure asphalt, it shows that the percentage increase in asphalt concrete quality occurs at the addition of 9% HDPE, PP and, mixture of Hof stability DPE and PP, 152%, 156%, respectively and 179%. This shows that the addition of plastic with a concentration of 9% can significantly improve the quality of concrete asphalt the main text (11 points).

| Variable combination       | Stabilisation (kg) | Flow (mm) | VIM (%) | VMA (%) | VFA (%) | MQ (kg/mm) |
|----------------------------|--------------------|-----------|---------|---------|---------|------------|
| Asphalt concrete 100%      | 1593.00            | 4.3       | 3.17    | 15.81   | 79.98   | 364.70     |
| Add 5% HDPE               | 1501.48            | 4.6       | 3.70    | 16.31   | 77.10   | 316.80     |
| Add 5% PP                 | 1807.33            | 3.9       | 3.90    | 16.45   | 76.31   | 444.88     |
| Add 5% HDPE and PP        | 1362.45            | 6.4       | 4.95    | 17.36   | 71.50   | 204.37     |
| Add 7% HDPE               | 1529.28            | 4.5       | 4.67    | 17.12   | 72.73   | 326.25     |
| Add 7% PP                 | 2015.88            | 4.7       | 4.26    | 16.77   | 74.57   | 412.00     |
| Add 7% HDPE and PP        | 1807.34            | 7.4       | 3.53    | 16.13   | 78.13   | 234.47     |
| Add 9% HDPE               | 2085.39            | 3.6       | 4.26    | 16.77   | 74.57   | 556.10     |
| Add 9% PP                 | 2850.03            | 4.8       | 3.85    | 16.41   | 76.52   | 570.00     |
| Add 9% HDPE and PP        | 2989.06            | 4.4       | 4.47    | 16.94   | 73.64   | 652.16     |

4. Conclusion
The most significant Marshal Question (MQ) test results were seen in samples from mixed asphalt with the addition of 9% plastic. The percentage increase in MQ value from the addition of 9% HDPE, PP, and HDPE: PP mixture, compared to the use of pure asphalt (100% asphalt) was 152%, 156% and 179%. This shows that the addition of plastic with a concentration of 9% can significantly improve the quality of asphalt concrete.

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