Stability Improvement of Asphalt Concrete Binder Course using LDPE Plastic Waste with Lignin as Coupling Agent

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Abstract. Development of plastic waste as an asphalt mixture is inhibited by its compatibility. In this study, the addition of weight variations modified lignin as coupling agent in Asphalt Concrete-Binder Course (AC-BC) with LDPE mixture was investigated. Asphalt, Polymer Modified Bitumen with and without lignin addition were characterized by physical analysis using Fourier Transform Infrared Spectroscopy and Scanning Electron Microscopy. While the AC-BC pavement was analyzed by mechanical analysis using marshall parameter. The addition of plastic to asphalt will form agglomeration and after lignin was added the agglomeration reduced. The reduced formation of plastic agglomeration due to lignin addition in asphalt form Van der Waals reaction was indicated by peaks alteration from 1041.77 cm⁻¹ to 1031.11 cm⁻¹ at the maximum addition of lignin. Moreover, the marshall stability of the AC-BC pavement was enhanced up to 89.5% at optimum lignin addition. Lignin utilization as a coupling agent of asphalt and LDPE can be a solution to the weaknesses of asphalt plastic technology while solving the plastic waste problem.

1. Introduction
Polymer modified bitumen (PMB) is a mixture of asphalt with polymer on mechanical and chemical methods. PMB is one of the development materials on road pavement construction. The effect of polymer addition to asphalt can improve asphalt stiffness, workability, and elasticity [1]. In fact, Development of plastic waste as an asphalt mixture is inhibited by its compatibility. Asphalt is Hydrophilic (polar) and plastic is Hydrophobic (non-polar) [2].

Additional plastic in asphalt will form plastic agglomeration. The effect of this condition will increase pavement stability parameter, but it will increase void in aggregate percentage [3]. In another research, has found that mixing asphalt with LDPE can improve asphalt physical characteristics. However, low compatibility between those materials forms plastic agglomeration when the temperature changes [4].

The coupling agent can be the solution of those materials [5]. There are some coupling agent those can be used, such as silane [6], γ-(methacryloyloxy) propyl trimethoxysilane [7] as aggregate asphalt binder, maleic anhydride in poly(ethylene terephalate) (PET) and Low Density polyethylene (LDPE) mixture [5],Titanate and lignin [8-9]. Those various types of coupling agents are able to improve asphalt quality, but lignin coupling agent has better distribution and dispersion compared to another coupling agent. Previous research has shown the result that lignin is also a phenolic polymeric compound. It is the derivative of three hidroxynamel alcohol which is p-coumaryl alcohol, coniferyl alcohol, and sinapyl
alcohol. These compounds make lignin has hydrophobic (Non-polar) and hydrophilic (Polar) parts that have potential as a coupling agent material [10].

In this study, we did research further on lignin addition on PMB with LDPE plastic waste. We decided AC-BC pavement layer as a bounding layer on asphalt concrete structure for research application on road mechanical analysis by Marshall test to control appropriateness of pavement stability and also from physical analysis on chemistry bond and morphological characteristics.

2. Materials and Methods

2.1. Materials
In this experiment, an optimal proportion of AC-BC mixture with polymer addition was used as control variable. This mixture consists of asphalt with penetration grade 60/70, rough aggregate and filler. While LDPE from plastic waste and modified lignin, sodium lignosulfonate were used as modifiers of asphalt.

2.2. Method
The Job Mix Formula of this research design was made based on Bina Marga Specification 2018. Total weight of the aggregate design using formula below

\[ Pb = 0.035 \%(CA) + 0.045\%(FA) + 0.18\%(FF) + K \]  

\( (Pb) \) is designed for asphalt percentage of mixture, \( (CA) \) is coarse aggregate in size \( >2,36 \) mm, \( (FA) \) is coarse aggregate in size \( 2,36-0.075 \) mm and \( (K) \) is constant for AC-BC layer about \( \pm 0.5 \). There were 5 variations of asphalt proportion, 5.15%, 5.65%, 6.15%, 6.65%, 7.15% of the total weight of the aggregate at once preparing various LDPE proportions 2%, 4%, 6% of such asphalt proportion design. Those LDPE proportions refer to previous research, there was a decreased stability parameter above the addition of 4% plastic waste. All of that material was mixed with controlled temperature at 150°C. Sampling material mixture according to the specified shape using marshall compactor for mechanical analysis by Marshall stability test, refers to 2018 Bina Marga General Specifications that has shown in table 1.1. This result would be an optimal proportion of asphalt+LDPE (PMB) that is modified with lignin addition.

In lignin addition analysis, variations in lignin content are 0.5%, 1%, 1.5%, 2% by weight of asphalt. Previous research has shown the optimum addition of lignin is 1.5% wt [11]. Using optimum proportion from previous analysis, mix all materials at a controlled temperature at 150°C and sampling for Marshall test to decide optimal proportion of AC-BC layer with LDPE polymer and lignin. For further research results, prepare asphalt, PMB, and PMB+lignin for characterizing chemical bonding and morphological by FTIR and SEM test as physical analysis.

### Table 1.1 Bina Marga Marshall Specification

| MIXED CHARACTERISTICS                  | ASPHALT CONCRETE |
|---------------------------------------|------------------|
|                                       | AC-WC | AC-BC | AC-BASE |
| Number Of Marshall Compactor          | 75    | 75    | 112     |
| Void In Mix (VIM) (%)                 | Min.  | 3     | 3       |
|                                       | Max.  | 5     | 5       |
| Void in Mineral Aggregate (VMA) (%)   | Min.  | 15    | 14      | 13     |
| Void Filled Asphalt (VFA) (%)         | Min.  | 65    | 65      | 65     |
| Marshall Stability (kg)               | Min.  | 1000  | 1000    | 2250   |
| Flow (Mm)                             | Min.  | 3     | 3       | 3      |
| Marshall Quotient (Kg/Mm)             | Min.  | 300   | 300     | 350    |
3. **Result and Discussion**

3.1. **Chemical bound characteristic**

The addition of lignin to asphalt allows the formation of ether compounds. The phenomenon that occurred was a shift in the peak from 1041.77 to 1037.56, 1032.34, 1031.36 and 1031.11 respectively after the addition of lignin. Those results indicated a weak bond (van der waals bond) by stretched C-O bond [12].

![Figure 1. Result of FTIR Spectra](image)

Estimates of the mechanism of lignin as a coupling agent on asphalt and LDPE are shown in Figure 1. The van der Waals bond was first formed due to the hydrolysis reaction between asphalt and lignin. However, the H-O-H bond was not seen at FTIR because the manufacturing process was carried out at 150°C, so the compound evaporated. The van der Waals bond that occurs between asphalt and bitumen plays a role in bringing the asphalt compound closer to the lignin compound because there is a force of attraction. As a result, asphalt compounds are unstable and tend to be more binding with LDPE compared to lignin.
3.2. Morphology identify

Figure 3. Morphological Surface of a) Pure asphalt b) PMB c) PMB + lignin

PMB morphology on Figure.3 showed that LDPE agglomeration was formed. LDPE agglomeration occurred because of differences in the properties of LDPE with asphalt which caused it not to be mixed evenly. Also, visible surface tension between agglomeration with asphalt is very high, indicated by the difference in color that is thick in the layers between, interphase, asphalt and LDPE. This condition will allow LDPE agglomerates to be the starting point for cracking. Meanwhile, after adding lignin, agglomeration does not appear. This confirms that lignin as a coupling agent on asphalt and LDPE plays a good role.

3.3. Marshall stability analysis

From the first Marshall stability test to determine the proportion of PMB, we determined the optimal proportion is about 5.65% asphalt + 6% LDPE with stability value improvement 17% than just using pure asphalt. In lignin addition analysis, an increase in the value of the stability up to 89.5% after the addition of lignin. As shown in Figure 4(a), the stability parameter optimum in lignin content of 1%. It is proven that the performance of lignin as a coupling agent between asphalt and plastic works well. So
that the compatibility of the AC-BC increases and the distribution of loads between asphalt and aggregates becomes more evenly distributed [13].

![Figure 4. Marshall Test Result (Parameter Diagram) of a) Stability  b) Void in Mix c) Flow  d) Void Filled Asphalt](image)

However, the addition of lignin > 1% reduces the stability value of the AC-BC. It is caused by lignin binding to one another and inhibiting the performance of lignin as a coupling agent [14]. Also, the percentage of air cavities in the mixture shown by the Void in Mix (VIM) parameter in Figure 4(b) has decreased only with the addition of 1% lignin. It is estimated that the addition of lignin is less than 1% too little, so that agglomeration in the mixture still occurs. While the addition of lignin of more than 1% causes a steric effect that inhibits Van der Waals bonds so that agglomeration continues to form [15]. The excess lignin added was confirmed by the surface morphology of the mixture of PMB and lignin in Figure 3 which continued to form agglomeration even though its size was smaller than without the addition of lignin.

The addition of lignin also affects fatigue parameters on asphalt pavement (Flow). From Figure 4(c), it indicates the AC-BC is more plastic because the addition of lignin increases the miscibility between asphalt and plastic thus increasing the softening point of PMB [13]. But this characteristic makes pavement more resistant to washboarding problems.

![Figure 5. Comparison of Stability Parameter](image)
For other parameters, decrease in VIM value also affects the portion of the air cavity amount of aggregates or Void in Mineral Aggregate (VMA). As a result, variations of lignin in levels of more than 1% have a Void Filled Asphalt (VFA) value be <65% which means that among mineral aggregates filled with PMB was measly because the effect of agglomeration has occurred [15]. These conditions make AC-BC that planned to be vulnerable bleeding on the road.

Based on all analyzes, the optimum proportion of the addition of a lignin coupling agent is determined by 1%. The comparison stability value as the main primary parameter of asphalt pavement shown in figure 5. As a result, the addition of 1% lignin can increase the stability of the AC-BC layer up to 89.5% compared to the use of only pure asphalt. These results are related with SEM and FTIR test results that the addition of lignin can improve compatibility between LDPE plastic waste and asphalt by optimum mixed proportion.

4. Conclusion
The addition of lignin to the AC-BC mixture layer can increase the stability value up to 89.5% (3375.92 kg) when compared to the use of pure asphalt (1781.40 kg). As well as being able to reduce the value of mixed VIM to conform with Bina Marga Specifications 2018. This research is able to be a solution to utilization of plastic waste, and improving the quality of pavement layers as well as being able to save costs on road construction.

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