Comparison Study Of Physical And Mechanical Properties Of AC-WC Mixtures And Porous Asphalt Mixtures With Variations Of Binding Materials

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Abstract. Pavement performance is influenced by the selection accuracy of material and gradation. AC-WC has good stability but low porosity, so that puddles often occur on the surface. While porous mixture has high porosity to reduce the puddles quickly but low stability. Therefore, modified asphalt is needed to improve the performance of the mixture. This paper presents an experimental laboratory study on the physical and mechanical performance of AC-WC and Porous asphalt mixture with Starbit E-55 and Pen 60/70. Laboratory works start with a physical test of all the material used, then, tests to find optimum asphalt content are conducted. Finally, test on Marshall properties and Index of Retained Strength (IRS) were run. Results showed that Starbit is more resistant to temperature than Pen 60/70. AC-WC mixture with Starbit has greater air void, 11% greater stability, 13% greater MQ, and IRS of the mixtures using Starbit were higher than those with Pen 60/70. While the Porous mixture with Starbit has greater air void, 22% higher stability, 13% greater flow, 9% greater MQ compared to Pen 60/7. This proves that the use of Starbit is more effective for improving the structural and functional performance of AC-WC and Porous mixture.

1. Introduction

AC-WC is a type of surface mixture of flexible pavement that is commonly used in Indonesia. In practice, AC-WC usually uses a conventional asphalt binder with Pertamina Pen 60/70, with the provisions that have been regulated by Bina Marga. However, damage to the pavement in Indonesia still occurs. According to [1], the dominant factors causing road damage consist of 3 (three) main factors, pavement construction quality factors, road surface drainage water factors, and vehicle load repetition factors. The Changes in weather also can reduce the pavement performance. The main factors of pavement damage due to weather are water and temperature. Therefore, innovation is needed to anticipate this situation. One of the solutions being developed in the world in overcoming the problems due to water is a Porous asphalt mixture. Porous asphalt mixture can drain puddles due to rain. Porous asphalt is an asphalt mix design with a higher percentage of coarse aggregate compared to the content of fine aggregate, resulting in large cavities so that water can drain [2]. However, mixtures with large amounts of voids or pores result in low stability values. Therefore, a variety of materials is needed that can improve the structural performance of Porous asphalt. For example, by the use of additives or the selection and use of high-quality and high-quality binding materials, so that they can answer these problems. This study is using variations asphalt binder, these are Pen 60/70 and the higher quality binder was Starbit-E55. The use of Starbit-E55 asphalt is predicted would improve the
structural performance of the Porous asphalt mixture. Starbit E-55 asphalt is a commercial polymer asphalt that has been added with added materials, so it has better quality than Pen 60/70.

The AC-WC mixture is designed to serve heavy traffic, therefore the AC-WC mixture has good stability and durability. However, damage often occurs due to weathering and repetition of the axle load. Innovation is needed to prevent damage to the asphalt pavement. [3] innovated on warm mix asphalt. It studied the mechanical property characterization of warm mix asphalt prepared with chemical additives. The additives used are Evotherm 3G and Rediset LQ-1106. Based on the results of these studies, the use of these additives can increase the value of Indirect Tensile Strength (ITS). Another innovation is the selection of the type of gradation. Pavement technology developed to anticipate the occurrence of damage due to puddles is Porous asphalt. According to [4], the surface layer of the road can pass water into the top layer (wearing coarse) vertically and horizontally through the capillary air pores with the pavement layer as a drainage system. Porous asphalt is an effective solution to improve traffic safety in very bad weather conditions (heavy rain and slippery). According to [5], the Porous asphalt mixture using the [6] has the highest permeability coefficient of 174 m/day. Another research of Porous asphalt innovation conducted by [7] regarding the Experimental Evaluation of Anti-Stripping Additives on Porous Asphalt Mixtures. Another study was conducted by [8], which used additives materials anti-stripping aging Wetfix-BE. Based on the results of the test, it is known that the escalation in the stability value is 6.72%, VMA is 1.34%, VITM value is 2.89% and the marshall quotient value increases, by the effect of adding 0.3% Wetfix-BE to the asphalt concrete mixture. The use of polymer asphalt can also be innovation and solution to overcome pavement problems. The Innovations of using polymer asphalt have been widely researched. [9] investigated the gradation of Superpave mixtures with the [10]. The use of polymer asphalt Starbit E-55 bonding material can increase the value of Marshall stability and durability, the ITS value is 45%, and the Cantabro Loss value is 22%, compared to the use of asphalt Pen 60/70.

Different from the previous study, this paper presents an investigation on physical properties of Starbit E-55 and Pen 60 70 and the use of those bonding materials on Porous asphalt and AC-WC mixtures, by comparing their volumetric properties, mechanical properties, and durability, based on Marshall standard [11] and [6]. In accordance with the description above, in this study, discussion on the comparison of the performance of Porous asphalt mixtures and AC-WC mixtures with variations of Pen 60/70 asphalt binder and Starbit E-55 polymer asphalt binder will be present in the following discourse. With this research, it is hoped that the selection and use of appropriate materials can be found so that solutions can be found for pavement problems that occur in Indonesia.

| Parameters                     | Starbit E-55 | Pen 60/70 |
|--------------------------------|--------------|-----------|
| Specific Gravity               | ≥ 1.0        | ≥ 1.0     |
| Penetration (0,1 mm)           | 50-80        | 60-70     |
| Ductility (cm)                 | ≥ 50         | ≥ 100     |
| Flash Point (°C)               | ≥ 225        | ≥ 232     |
| Fire Point (°C)                | ≥ 225        | ≥ 232     |
| Softening Point (°C)           | ≥ 54         | ≥ 48      |
| TCE Solubility (%)             | ≥ 99         | ≥ 99      |

2. Materials and Methods
Asphalt Pen 60/70 used is produced by PT Pertamina, while Starbit E-55 is made by PT Bintang Jaya. The binder materials properties test results are demonstrated in Table 1. Coarse and fine aggregates
and filler used are taken from the local region, known as Clereng. Table 2 shows the physical properties result of aggregates. The mixture standard used is Bina Marga (2018) for the AC-WC mixtures and AAPA (2004) for Porous asphalt mixtures. The design gradation for AC-WC mixture and Porous asphalt mixture can be seen in Figure 1 and Figure 2.

Table 2. Aggregate Properties

| Parameters                  | Coarse | Fine | Filler |
|-----------------------------|--------|------|--------|
|                             | Standard | Result | Standard | Result | Standard | Result |
| Specific Gravity            | ≥ 2,5  | 2,6601 | ≥ 2,5  | 2,6271 | ≥ 2,5  | 2,6271 |
| Water Absorption (%)        | ≤ 3    | 1,686  | ≤ 3    | 2,35   | -      | -      |
| Adhesiveness (%)            | ≥ 95   | 98    | -      | -      | -      | -      |
| Abrasion (%)                | ≤ 40   | 12,97 | -      | -      | -      | -      |
| Sand Equivalent (%)         | -      | -     | ≥ 50   | 91,891 | -      | -      |

The test carried out to obtain the optimum asphalt content (OAC) of AC-WC mixture was Marshall test, while, for Porous asphalt mixture, there were Marshall test, Cantabro Loss (CL) test, and Asphalt Flow Down (AFD) tests. The graph of the method for determining OAC of AC-WC mixture using Pen 60/70 and Starbit E-55 based on the Marshall test is shown in Figure 3 and Figure 4. Meanwhile, the graph of the relationship between asphalt content and VITM, Cantabro Loss and AFD value, and a method for determining of OAC of Porous asphalt is plotted in Figure 5 to Figure 6.
The optimum asphalt content obtained in the AC-WC mixture using Pertamina Pen 60/70 asphalt is 6.1% of the total weight of the mixture. While the AC-WC mixture uses Starbit E-55 asphalt which is 6.2% of the total weight of the mixture.

**Figure 3.** Determination of OAC Pen 60/70  
**Figure 4.** Determination of OAC Starbit E-55

**Figure 5.** VITM for Determination of OAC Porous Asphalt  
**Figure 6.** Cantabro Loss for Determination of OAC Porous Asphalt

**Figure 7** Asphalt Flow Down for Determination of OAC of Porous Asphalt
The OAC obtained for Porous asphalt using Pen 60/70 was 5.55% of the total weight, while for using Starbit E-55 was 5.6% of the total weight of the mixture.

3. Result and Discussion
The Data of the Marshal Test were analyzed to identify the performance of mixture type and binder variation. The analysis explains the volumetric properties of Marshall, including void in the total mix (VITM), void filled with asphalt (VFWA), void in mineral aggregates (VMA), and density, as well as mechanical properties such as stability, flow, and MQ. Figure 8 and Figure 9 present VITM and VFWA of the mixture at OAC.

![Figure 8. VITM of Porous and AC-WC at Optimum Asphalt Content](image)

![Figure 9. VFWA of Porous and AC-WC at Optimum Asphalt Content](image)

It can be seen from Figure 8 that VITM of the Porous asphalt mixture is six times much greater than the VITM value of the AC-WC mixture. In accordance with the design objectives of the Porous asphalt mixture, this mixture is designed to be able to pass water on the surface of the pavement. The use of Starbit E-55 produces a higher VITM value than the use of Pen 60/70 in both types of mixtures. This condition caused by the Starbit E-55 has a lower Penetration grade. [12] stated that the use of polymer asphalt in Porous asphalt mixtures can increase the VITM to be greater than the use of Pen 60/70. This study is also in consistent with many previous researcher [9]; [13]; [14]; and [15]. They found out that a higher value of VITM is affected by the nature of a polymer asphalt of Starbit E-55, which has a more viscosity than Pen 60/70 at the same temperature.

As shown in Figure 9, the VFWA of the AC-WC mixture is much greater than that of the Porous asphalt mixture. This is due to the gradation used. AC-WC mixture is a continuous gradation type so that the aggregate distribution in this mixture is more even equal. Pen 60/70 more fills the void of the AC-WC mixture. Meanwhile, the Porous asphalt mixture is slightly different due to the open gradation, it is not evenly equal distributed. The higher VFWA of the mixture indicates that the voids in the mixture are more filled with asphalt. This condition caused by the Pen 60/70 has a higher Penetration grade and lower viscosity, so that it is easier to fill the voids. The use of modified asphalt with a higher penetration rate will increase VFWA in the AC-WC mixture. This also is in regards with [9]; [13]; [14]; and [15].

The bar chart of Void in mineral aggregates and density of Porous asphalt and AC-WC are depicted in Figure 10 and Figure 11.
As can be seen in Figure 10, AC-WC mixtures have a significantly lower VMA than Porous asphalt. [15] stated that VMA shows the distance between aggregates under certain conditions. The mixture with higher VMA indicates that it has a thicker film asphalt covering the aggregates. The greater VMA indicates the strain between the aggregate particles. This can be caused by two things, namely the larger the pore value of the mixture or the thicker the bitumen layer on the aggregate. AC-WC is a dense graded mixture which only has a very low void, compare to Porous asphalt. This is because of the use of fine aggregates in Porous asphalt is very limited to achieve higher void in the mixture, this means that a distance between mineral aggregates in Porous asphalt is much higher than in AC-WC, as figured in its VMA. The use of Starbit in the mixtures obtain lower VMA of AC-WC than those with Pen 60/70. This is because of a lower penetration grade of Starbit E-55 so that it makes the asphalt harder to penetrates to the void, as a result, an only smaller amount of bitumen covering the aggregate. This is in contrast with the results concluded by [16], which explain that there was no significant difference between the VMA of Starbit E-60 and Pen 60/70, however, a slightly higher VMA of mixture using Starbit was also found.

Figure 18 exhibits that both AC-WC mixtures have a significantly higher density than Porous asphalt mixtures. This is because of Porous asphalt is designs to have higher voids to allow water to pass and drain the mixture, as a result, the mixture becomes open and has only less density. In regards to binding materials, it can be seen that the mixture using Pen 60/70 produce a slightly higher density than the mixture with Starbit E-55. According to [17], the properties of Pen 60/70 bitumen are easy to melt due to the relatively higher penetration grade and viscosity of this type of bitumen. This is consistent with the research run by [17].

Volumetric properties of Marshall such as VITM, VFWA, VMA, and density are important parameters that greatly influence the mechanical performance of the mixture, especially the structural performance such as stability, flow, Marshall Quotient (MQ), and tensile strength of the mixture. The stability and flow of Porous asphalt and AC-WC mixture are presented in Figure 12 and Figure 13. According to Figure 12, stability of the Porous asphalt mixture is significantly lower than the stability of AC-WC mixture, due to the Porous asphalt mixture is planned to serve low traffic, while the AC-WC mixture is designed to serve high traffic. This is also because of the void (VITM) of Porous asphalt is much higher than AC-WC, therefore, interlocking and interparticle friction in Porous asphalt is is much smaller than AC-WC, resulting in lower stability of this mixture. The mixture using Starbit E-55 generates higher stability than using Pen 60/70, because of the lower Penetration grade of Starbit E-55. This can prevent the deformation, and it will be more stable in holding the load. [18] did an investigation on the use of asphalt polymer, and concluded that based on physical testing of PG-67 polymer asphalt which has a lower Penetration grade, stability of the mixture using it were higher than those with a higher penetration grade. This also is in line with [9]; [13]; [14]; [15]; [16]; and [17].
Figure 12 shows that the Porous asphalt mixture has a higher flow value due to the mixture having a larger internal void so that the mixture following a larger deformation before plastic deformation occurs. Starbit E-55 produces a slightly higher flow mixture, because Starbit E-55 is an elastomeric polymer modified asphalt. Meanwhile, AC-WC mixture using Pen 60/70 has a slightly larger flow value caused by the continuous gradation is denser and plastic deformation occurs easily. [14] stated that the flow value of the AC-WC mixture using Pen 60/70 and Starbit E-55 is almost similar. According to his observation, different flow values are influenced by the volumetric value of the mixture. The higher flow value causes the mixture to be more elastic, while a lower flow value causes the mixture to be stiffer and easier to crack. Marshall properties that can be used to indicate the stiffness of the mixture is Marshall Quotient. The relationship between mixture types and Marshall Quotient is shown in Figure 14, while Figure 14 describes index of retained strength (IRS), which indicates durability of the mixture.

As depicted in Figure 14, the Marshall Quotient of Porous asphalt mixture is significantly lower than AC-WC mixture. This occurs because of Porous asphalt mixture has lower stability, and it is designed to have a higher flow value to allow greater deformation without cracking or plastic deformation, therefore, it produces a mixture with low MQ. Mixture with higher MQ tends to be stiffer and more brittle. Meanwhile, a mixture with a lower MQ could become more flexible but less...
stable. In general, the use of Starbit E-55 in all mixtures generates higher MQ mixtures, than those with Pen 60/70. This occurs because of the hardness of Starbit E-55, as mention earlier. [12] and [14] stated that MQ value of mixture using polymer asphalt is greater than Pen 60/70 due to their higher stability. This results is also in accordance with [9]; [13]; [14]; [15]; [16]; [17] and [19].

Based on Figure 15, the IRS of the AC-WC mixture is bigger than the Porous asphalt mixture. This is because of less fine aggregates in the Porous asphalt mixture compared to AC-WC. As a result, AC-WC mixture is denser and only has less air void (VITM). The higher the VITM, the more easily for water to penetrate to the mixture to disturb the integrity of the mixture. [20] stated that a mixture with more fine aggregate content will have a higher IRS value. This is related to the founding of [19], which stated that the smaller air void of mixture, the greater the resistance of the mixture to receive compressive forces, and it would increase the durability of the mixture. AC-WC mixture using Starbit E-55 has the highest IRS value of 92.02%, due to higher Penetration index (PI) of Starbit E-55, which causes higher resistance to temperature, compared to Pen 60/70. According to [13], the resistance of the mixture using Starbit E-55 was better than the mixture using Pertamina Pen 60/70.

4. Conclusion
The results of the analysis show that the performance of the physical and mechanical properties of the AC-WC mixture and the Porous asphalt mixture is better when Starbit E-55 polymer asphalt is used as a binding material, compared to the use of Pen 60/70. Starbit E-55 has a higher hardness, so the stability of the AC-WC mixture is 11% greater, and Porous asphalt mixture is 22% higher than those with Pen 60/70. Resistance to the temperature of Starbit E-55 influences the durability of the mixture against water and temperature, so that, the IRS of the mixtures using Starbit E-55 were higher than those with Pen 60/70. Likewise, the air voids in the Porous asphalt mixture using Starbit E-55 were significantly greater than those with Pen 60/70. This evidence that Starbit E-55 would be more effective in improving the structural and functional performance of AC-WC mixtures and Porous asphalt mixtures.

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