Comparative Study of Marshall Properties and Durability of Superpave and AC-WC Pavement by Using Starbit E-55 and Pen 60/70

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Abstract. The challenges in high traffic volumes, excessive loads and environmental problems need to be anticipated through modification of pavement materials, both for gradations as well as for binding materials. This paper presents a comparative study of Marshall characteristics and its durability between Superpave and AC-WC graded mixtures using Starbit E-55 and Pen 60/70. The experimental laboratory begins with physical testing of aggregate and bitumen material, then, determination of optimum bitumen content for each of the mixture was conducted, and Marshall Standard and Index of Retained Strength (IRS) at optimum bitumen content were then run. Results show that in general Superpave mixture with Starbit has a significantly better Marshall performance in terms of its stability and Marshall Quotient, however, its volumetric properties, such as void in total mix, void filled with asphalt and density were slightly lower quality than AC-WC. It also has proven that Starbit E-55 gives a significantly better mechanical performance on Superpave mixture rather than on AC-WC, with only a slightly lower volumetric quality. Superpave mixtures tend to have a more durable performance then the AC-WC mixture. It also has been found that Starbit E-55 generates a more significantly durable mixture of Superpave rather than on AC-WC.

1. Introduction
Indonesia is currently in dire need of innovation or modification for progress towards the development of transportation support facilities, one of which is road pavement structure. The increasing number of traffic and the very rapid development of vehicles as well as the challenges of environmental problems have resulted in the need for pavements in anticipating problems caused by extreme weather factors, high traffic volumes, and excessive loads. Thus, this challenge needs to be anticipated through modification or looking for other alternative pavement materials, both for various types of gradations or types of binding materials.

One type of gradation that is possible to be applied in Indonesia is Superpave. This type of mixture has developed rapidly in its use and application in America. Superpave mixture is developed by the Strategic Highway Research Program (SHRP, 1994). Superpave stipulates the specification requirements for gradation targets with the presence of a prohibition zone in the form of maximum and minimum nominal sizes for each hot mix bitumen design to reduce the effects of plastic deformation and initial cracking due to the repeated vehicle or traffic loads. [1] explain that the gradation zone of the prohibition on the Superpave mixture will provide a larger volume of voids, with the hope that the bitumen used can fill the voids to the maximum. According to [17], Superpave mixture can reduce the effects of plastic deformation and early cracking due to repeated traffic loads. In addition, [11] and [23] stated that Superpave can prevent performance degradation due to extreme conditions, so it is very

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effective to apply, especially in countries with extreme climates. [13] stated that Superpave mixture is recommended because of its resistance to permanent deformation, so Cirit > 89%. To anticipate plastic deformation due to traffic compaction, it is recommended that Cmax > 98%. This indicates that the voids in the VITM mixture must be > 2%.

The use of the binding material types also has an important role in efforts to improve and maximize the performance of road pavements. [7] conducted a study on 2 aspects, namely the effect of different types of mixed gradations and types of binding materials on the characteristics of a pavement mixture. The study used five types of gradations with two different types of binding materials. In the conclusion of his research, it was found that the optimum bitumen content and varying pavement performance for each type of gradation and binding material were very different from one another. In Indonesia, several types of modified binding materials can be used as alternative options, one of which is Starbit E-55 modified binding material.

Starbit E-55 is a commercial modified asphalt product owned by PT Bintang Jaya. This type of asphalt has been modified in the form of adding addictive ingredients so that the quality is better than conventional asphalt which is often used in Indonesia. Research using Starbit E-55 as a binding material has been published in several journals such as research journals conducted by [14], [22], [9], and [8]. The use of Starbit with different penetration types also can increase the initial pavement characteristics. According to [19] the pavement mixture with Starbit E-60 was more resistant to impact or abrasion compared to the mixture with Pen 60/70. This is due to the content of the elastomer-based Starbit E-60 so that it has better strength and elasticity to overcome the impact of impact that occurs.

Based on previous studies described above, it can be concluded that the use of Superpave and Starbit E-55 as a binding material can be used as an alternative to road pavement problems in Indonesia. However, an exploration to find out how much the increase in pavement performance is due to the influence of gradation type of Superpave and the Starbit E-55 as a binding material is still significant to be carried out. In this paper, a study on Marshall properties and durability, in terms of Index or Retained Strength (IRS) of Superpave and AC-WC using Starbit and Pen 60/70 as binding material are explored.

2. Research Method
Two types of different hot mix bitumen mixture, namely Superpave and AC-WC and two types of bitumen, which are Starbit and Pen 60/70 were used as binding material. Coarse aggregates, fine aggregates and filler were obtained from Clereng query, Pen 60/70 were produces by PT. Pertamina, and Starbit E-55 were made by PT. Bintang Jaya. The initial stage material properties testing of aggregates, Starbit E-55, and Pen 60/70, then, determination of optimum bitumen content (OBC) for each mixture and bitumen type were carried out. Based on OBC, Marshall properties testing and Immersion test of IRS specimens for each mixture variation then were conducted. The number of specimens needed for obtaining OBC is 60 specimens, while 24 specimens were used to investigate Marshall properties and IRS.

3. Result and Discussion

3.1. Material properties
Aggregates and bitumen results testing can be seen in Table 1 and Table 2 below.

| Parameters                          | Spec. | Coarse | Fine  |
|-------------------------------------|-------|--------|-------|
| Specific Gravity                    | ≥ 2.5 | 2.73   | 2.69  |
| Water Absorption/porosity (%)       | ≤ 3   | 1.89   | 2.13  |
| Adhesion of Aggregates-Asphalt (%)  | ≥ 95  | 95     | -     |
| Abrasion (%)                        | ≤ 40  | 19.5   | -     |
| Sand Equivalent (%)                 | ≤ 50  | -      | 91.9  |

Table 1. Aggregate Physical Properties
Table 2. Bitumen Physical Properties

| Parameters                  | Starbit E-55 | Pen 60/70 |
|-----------------------------|--------------|-----------|
| Spec. Result                | Spec. Result |
| Spesific 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      |
| Penetration Index           | -            | -1.18     |
| Sbit (MPa)                  | -            | 5.6       |

3.2. Marshall Properties at Various Bitumen Content

A review of Marshall’s characteristics of Superpave and AC-WC mixture using Starbit E-55 and Pen 60/70 in correspond with bitumen content can be seen as follows.

3.2.1. Void in Total Mix (VITM)

The relationship between bitumen content and VITM of Superpave and AC-WC mixtures can be seen in Figure 1 and Figure 2.

![Figure 1](image1.png)

**Figure 1.** The Effect of Bitumen Content on VITM of Superpave

![Figure 2](image2.png)

**Figure 2.** VITM of AC-WC with regards to Bitumen Content

Based on Figure 1 and Figure 2, it can be seen that the higher the bitumen content used, the lower the VITM of the mixture. The decrease of the VITM is caused by the increasing number of bitumen filling the voids in the mixture, so that the remaining air voids become smaller. For mixtures with Starbit E-55, they show that the VITM tends to be higher than that of Pen 60/70 and they have a lower decreasing trend at each grade. This is because the hardness and viscosity of Starbit E-55 are higher than Pen 60/70, as seen in the results of penetration testing material (Table 2). These results are in regards to research conducted by [8], [9], [22], [6], and [14]. These researchers found out that the low VITM of the mixture containing Starbit E-55 was due to its relatively slightly higher viscosity compared to Pen 60/70 bitumen.

3.2.2. Void Filled with Bitumen (VFWA)

The VFWA of Superpave and AC-WC mixtures in relation to bitumen content are plotted in Figure 3 and Figure 4 below.
It can be seen from Figure 3 and Figure 4, that the higher the bitumen content used, the increasing of VFWA of the mixtures. Volumetrically, the mixtures using Pen 60/70 have higher VFWA than those with Starbit. This is because Pen 60/70 has a higher penetration value and lower penetration index, compare to Starbit E-55. This result is in line with the previous research conducted by [8], [9], [6], and [13]. The higher VFWA shows that the Pen 60/70 bitumen is relatively more sensitive to temperature changes so that it will be easier to fill the voids in the pavement mixture.

3.2.3. Void in Mineral Aggregate (VMA)

The graph of the relationship between bitumen content and VMA of Superpave and AC-WC mixtures are shown in Figure 5 and Figure 6.

Figure 5 and Figure 6 show that the curves of VMA for each type of mixture continue to increase along with the addition of bitumen content used. This is because bitumen functions as a lubricant during compaction so that it helps aggregate to occupy its position so that the mixture becomes tight, which is indicated by a decreasing curve of VMA. The VMA of the mixtures using Starbit E-55 tends to be higher than those with Pen 60/70. This is because Starbit E-55 has an impact on the VITM value in the pavement mixture so that along with the increasing bitumen content, the VMA in the mixture will increase. The VMA of the mixture using Starbit E-55 are higher compared to those with Pen 60/70. This result is consistent with previous research published by [22], and [6].

3.2.4. Stability

The effect of bitumen content on the stability of Superpave and AC-WC mixtures are shown in Figure 7 and Figure 8.
3.2.5. Flow

The curve of the flow of Superpave and AC-WC mixtures correspond to bitumen content are depicted in Figure 9 and Figure 10.

As can be seen from Figure 9 and Figure 10, the curve of flow is rising along with the addition of bitumen content. The increasing of flow is the impact of increasing the thickness of the bitumen layer that covers the aggregate so that the flexibility of the bitumen is go up and results in a change in shape (plastic deformation). The use of Pen 60/70 bitumen in Superpave as well as AC-WC produce the higher flow of those mixtures. This is because Pen 60/70 has a higher penetration value, lower softening point and more sensitivity to temperature compare to Starbit [8], [9], and [14] and has a value. So with these parameters, it is resulted that the use of Pen 60/70 produces a higher flow of mixtures compared to Starbit E-55.
Based on the overall test results in all variety of bitumen content, an optimum bitumen content (OBC) for all the mixtures were obtained (Table 3).

| Jenis Campuran | Optimum Bitumen Content (%) |
|---------------|-----------------------------|
| Superpave     | Starbit E-55: 6.1            |
|               | Pen 60/70: 6.0               |
| AC-WC         | Starbit E-55: 6.2            |
|               | Pen 60/70: 6.1               |

As can be seen from Table 3, there is no significant bitumen optimum content among all the mixtures. However, it seems that on the same types of a mixture, the mixture needs more Starbit E-55 than Pen 60/70. In term of the mixture, it looks that optimum content of bitumen of Superpave is lower than AC-WC.

3.3. Marshall Properties and Indirect Retained Strength at Optimum Bitumen Content

The effect of the use of Starbit E-55 and Pen 60/70 on the Marshall properties of Superpave and AC-WC mixtures is described as follows.

3.3.1. Void In Total Mix (VITM) and Void Filled With Asphalt (VFWA)

The comparison between the VITM and VFWA Superpave and AC-WC using Starbit E-55 and Pen 60/70 are shown in Figure 11 and Figure 12.

Figure 11 shows that both Superpave and AC-WC using Starbit significantly have higher VITM than that of mixtures using Pen 60/70. [1] their research explain that the gradation zone of prohibition in the Superpave mixture will provide a role in the form of a larger volume of voids, with the hope that the bitumen used can fill the voids to the maximum. It is also known that the pavement mixture using Starbit E-55 has a relatively higher VITM value than the use of Pen 60/70, and the AC-WC mixture using Pen 60-70 has the lowest void among others. This seems in line with research conducted by [8], [9], [22], [6], [14] and [20]. Most of them found out that the higher value of VITM is influenced by the nature of Starbit E-55 which is more viscous than Pen 60/70 at the same temperature.

It can be indicated from Figure 12, that AC-WC contains Pen 60/70 has significantly highest VFWA among other mixtures. In general, it is also clear that Superpave mixtures have lower VFWA than AC-WC. [2] explained that with the use of a more dominant proportion of fine aggregate in the pavement mixture, the pavement voids formed will be smaller. The mixtures using Pen 60/70 have a relatively higher VFWA compare to those with Starbit E-55. The higher VFWA of the mixture using Pen 60/70 is because of bitumen susceptibility to temperature (Table 2), in which its penetration index is only -1.17, while penetration index of Starbit E-55 is of 0.169, so that it will be easier to fill the voids in the pavement mixture. The results of these studies are following previous researcher [14], [22] and [8].
3.3.2. Void In Mineral Aggregate (VMA) and Stability

The VMA and density of Superpave and AC-WC using Starbit E-55 and Pen 60/70 are presented in Figure 13 and Figure 14.

![Figure 13. VMA of Superpave and AC-WC at Optimum Bitumen Content](image1)

![Figure 14. Stability of Superpave and AC-WC at optimum Bitumen Content](image2)

As can be explored in Figure 13, AC-WC mixtures have a significantly higher VMA than Superpave. The higher VMA of the mixtures is the result of the correlation between the high value of VFWA obtained and the relatively low value of the existing VITM. [18] stated that VMA shows the distance between aggregates under certain conditions. The greater the value of VMA, it 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. Following the statement of [1], Superpave mixture will provide a larger volume of voids, with the hope that the bitumen used can fill the voids to the maximum. It also can be seen that for Superpave mixture, the bitumen content is still possible to be added because of the available space to accommodate bitumen so that pavement mixture will have better performance. [2] also explained that, as the bitumen content increases, the VMA value will tend to decrease until it reaches the minimum point and then it rises again according to the addition of bitumen content. This is because bitumen will fill the voids between the aggregates until the voids can no longer be filled by bitumen, in this case the VMA value will be minimum.

When it is viewed from the effect of bitumen on the mixture, the pavement mixtures using Starbit E-55 have a significantly higher VMA than those with Pen 60/70. This is the impact of bitumen penetration index which is included in the criteria for low sensitivity to temperature when it is set a compared to Pen 60/70. Regarding the higher VMA of the mixture containing Starbit E-55, [22] explain that the higher VMA value in mixture with Starbit E-55 is due to lower penetration and a higher softening point of bitumen, so that in the mixing process it is more difficult to fill the voids between the aggregate particles, as a result, an only smaller amount of bitumen covering the aggregate. This is in contrast to the results concluded by [19], which explain in their research that there was no significant difference between the VMA of Starbit E-60 and Pen 60/70, however, a slightly higher VMA of the mixture using Starbit E-60 was found. The difference insignificance in the current study with that of [19] is possible due to the difference in the penetration value and the softening point value. In the current study penetration of Starbit is 55.8 mm and the softening point is 54°C, as for the previous study, the penetration value was 62.3 mm, and softening point was 48°C.

Based on the research results presented in Figure 14, it can be seen that the stability mixtures using Starbit E-55 were significantly higher than that with Pen 60/70. This is because of the hardness of the Starbit E-55 which has a penetration value of 55.8 mm, while Pen 60/70 is 61.5 mm. It means that at the same temperature Starbit E-55 is harder than Pen 60/70, so that higher resistance to deformation was generated by the mixtures using Starbit. These results are following the research performed by [8], [9], [22], [6], and [14]. [5] have also proven that the use of polymer-based bitumen will contribute to
increase the hardness of bitumen and the higher resistance to rutting deformation of the mixture, making them more suitable to be applied to roads with extreme climates and high vehicle volumes.

In Figure 14 is also been known that based on the type of gradation of the mixture, Superpave mixtures have significantly higher stability than AC-WC mixtures. This is because one of the advantages of the Superpave is their interlocking ability of aggregate and bitumen in the mixture. [17] has explained that this type of gradation has a prohibition zone, which is intended to provide an opportunity for bitumen to fill the pavement mixture. Regarding the interlocking capability, [16] stated that the use of a high enough bitumen content in a pavement mixture will make the bitumen performance less effective in covering the aggregate, in which, in this study, the optimum bitumen content of AC-WC mixtures was found higher than the Superpave mixture.

3.3.3. Flow and IRS

The curve of stability and flow of Superpave and AC-WC using Starbit E-55 and Pen 60/70 are shown in Figure 15 and Figure 16.

**Figure 15.** Flow of Superpave and AC-WC at optimum Bitumem Content

**Figure 16.** IRS of Superpave and AC-WC at optimum Bitumem Content

*Figure 15* reveals that the value of the flow of Superpave mixtures was significantly higher than AC-WC. [12] explained that bitumen concrete mixtures that use a dominant coarse aggregate (below the restricted zone) will produce a higher flow value when it was compared to a mixture of tons of bitumen that uses a more fine aggregate (above the restricted zone). In addition, the high flow value of the Superpave mixture is also caused by the supporting factor in the form of a prohibition zone that allows bitumen to enter the void between the aggregate particles of the Superpave mixture. According to [21], the Superpave gradation can be categorized as a gap graded type because the use of fine aggregate is small or limited. However, this gradation is not in the form of an envelope, but based on a control point which is the permissible limit on the size of the sieve grains, so that it is useful for improving the service level of the road pavement layer.

In terms of bitumen types, as also can be seen in *Figure 15*, mixtures with Starbit E-55 tend to have lower flow than those with Pen 60/70. This was because of the hardness and temperature susceptibility of Starbit, as mention in the previous discussion, the higher flow value of Pen 60/70 is caused by the lower the softening point value, namely 48°C, and 54°C for Starbit E-55. Based on the penetration index, it was found that bitumen Pen 60/70 was more sensitive to temperature. This result is in regard to the previous researcher [8], [9], [22], and [14], [10] also point out that polymer-modified bitumen will reduce bitumen properties in the form of reducing susceptibility to temperature. [6] also concluded that Pen 60/70 bitumen is more sensitive to temperature when compared to Starbit E-55 bitumen. In addition, the viscosity value of Pen 60/70 bitumen is higher than that of Starbit E-55 bitumen, so that Pen 60/70 was easier to flow in the void mixture.

Based on *Figure 16*, the chart shows that mixtures with Starbit E-55 tend to have a higher retained strength than those with Pen 60/70. This is a positive impact of the use of polymer bitumen so that the
sensitivity of bitumen to temperature changes is reduced. This temperature susceptibility will affect the durability of Starbit E-55 bitumen and the mixture. This is consistent with the investigation of [6]. In their study, they concluded that the pavement mixture using Starbit E-55 has more resistance to immersion.

4. Conclusion

Based on the results data analysis and the discussions several conclusions are presented as follows.

1. The use of the Superpave mixture in comparison with AC-WC has proven to result in a significantly better mechanical property, such as mixture stability, however, volumetric properties of VITM, VFWA and VMA of Superpave mixture is a slightly lower performance were also generated. As for the effect of the bitumen type, the mixture using Starbit E-55 have significantly higher stability than those with Pen 60/70, in contrast, Starbit E-55 produces a finely lower volumetric performance of mixtures than those with Pen 60/70. It also has proven that polymer bitumen of Starbit E-55 gives a more significant mechanical performance on Superpave mixture rather than on AC-WC, with only a slightly lower volumetric quality.

2. Superpave mixtures tend to have a more durable performance than the AC-WC mixture. The use of Starbit E-55 generates significantly better durability of Superpave as well as AC-WC mixture. The highest Index of retained strength of mixture is obtained in Superpave using Starbit E-55. It also has been found that Starbit E-55 generates a more significantly durable mixture of Superpave rather than on AC-WC.

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