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Comparative Study of Marshall Properties and Durability of Superpave Pavements Using Pen 60/70 and Starbit Pg-70 Binding Materials with Fly Ash

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Abstract

The challenges of increasing vehicle volume and extreme loads must be anticipated through pavement materials for gradations and bonding materials. This paper compares Marshall's properties and durability of Superpave pavements using Starbit Pg-70 and Pen 60/70 binder materials with Fly Ash substitution. The laboratory experiment begins with physical testing of aggregate and bitumen materials, then determines the optimum bitumen content for each of the mixtures with 0%, 50%, and 100% substitution for each type of binding material. A series of tests are carried out in the form of Marshall Standards and Index of Retained Strength (IRS), Indirect Tensile Strength (ITS), Tensile Strength Ratio (TSR), and Wheel Tracking at each optimum bitumen content. The results show that, in general, the use of Starbit Pg-70 binder has much better Marshall performance in terms of stability and Marshall quotient. Substitution of Fly Ash as fillers can also improve mechanical performance, with the advantage of increasing the value of Marshall Stability. Fly Ash fills the voids, so it has strong interlocking properties.

Keywords*: superpave; fly ash; Starbit Pg-70*

1. Introduction

Indonesia's economy is experiencing significant growth, characterized by a surge in industrial activities leading to increased transportation volume. Infrastructure development must be carried out to support economic development. Highways are one of the facilities that should not be ignored. Excessive and repetitive loads are one factor that can reduce road pavement performance as a means of transportation. Road infrastructure can experience damage, such as changes in surface shape due to excessive loads and repeated loads, so the materials that make up the pavement greatly influence the strength and durability of the pavement against traffic loads.

Superpave is a gradation type that can be implemented in Indonesia and has witnessed swift adoption and widespread use in the United States. Superpave mixture is a gradation of asphalt concrete mixture developed by the Strategic Highway Research Program (SHRP). According to (Fauziah et al., 2014), a Superpave mixture is able to reduce the effects of plastic deformation and initial cracking caused by repeated traffic loads. Furthermore, (Karahançer et al., 2018) and (Zumrawi et al., 2016) state that the Superpave pavement type is able to avert performance degradation because of extreme conditions, so it is adequate for application in countries with extreme climates. (Nono, 2010) stated in his research that the Superpave mixture is recommended so that the mixture is resistant to permanent deformation, so C_max > 98%. This suggests that the VITM mixture should have voids exceeding 2%.

In addition to the significance of gradation, the choice of binding material plays a crucial role in enhancing and optimizing road pavement (Hadi et al., 2021). The investigation focused on two main elements: how different pavement types and various binding materials affect the properties of a pavement mix. Superpave and AC-WC were the two pavement types under scrutiny in this study. The research results underscored that the optimal bitumen content and pavement performance differed significantly for each grade and binding material, highlighting the distinct impact of these factors. In Indonesia, several modified binding materials are available as alternative options, with one notable example being the modified Starbit PG-70 binding material.

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Starbit is a commercial binding material that has been given additives (PT. Bintang Djaja, 2013), so there is an increase in quality compared to conventional pavement binding materials, which are often used in Indonesia. A number of studies using Starbit have been published in various journals, including research journals conducted by (Pangaraya, 2015), (Yusuf et al., 2017), (Nugroho et al., 2018), and (Hadi et al., 2019). The use of Starbit as a bonding material with different types of penetration can improve the characteristics of the same initial pavement. According to (Subarkah et al., 2020), in their study using as a modified binding material, Starbit E-60 demonstrated more excellent resistance to impact or abrasion in pavement mixtures compared to those using Pen 60/70 binder. This heightened resistance can be attributed to the elastomeric nature of Starbit E-60, which provides elasticity and strength that effectively mitigate the impact of collisions.

In addition to the role of gradation and the type of bonding material, fillers also have a critical function in improving pavement quality. The filler serves to fill the voids between the aggregates. The use of filler in the pavement mixture is very influential in the formation of road texture and road strength. The materials that are often used as fillers are rock ash, lime, and Portland cement. The use of filler on pavements is required in large quantities, so the use of filler can affect the cost of pavement construction. One way to overcome the pavement construction cost is by using existing waste. Coal fly ash can be used as a filler substitute.

Coal is one of the fossil fuels in Indonesia, and its availability is estimated at 38.9 billion tons. Of the 38.9 billion tons, around 67% are in Sumatra, 32% are in Kalimantan, and the rest are in Java, Sulawesi, and Irian Jaya (Wardani Sri Prabandiyani Retno, 2008). Fly ash basically cannot bind, but in the presence of fine-sized particles and added to the presence of water, the silica oxide contained in fly ash will [cause a chemical reaction with calcium hydroxide, which produces a substance that is able to bind. This makes Fly Ash an alternative to a mixture of road pavement layers. Using fly ash as a mixture of road pavement aims to reduce environmental pollution. The utilization of fly ash for road pavement layers must have the right proportions to optimize its utilization.

Based on the results of the studies that have been described, using pavement with the Superpave gradation type and using Starbit binding material with the addition can be an alternative to overcoming road pavement difficulties in Indonesia. However, an investigation to determine how much the road pavement performance has increased due to the influence of the Superpave gradation type with Starbit PG-70 binder and the addition of fly ash still needs to be done. In this research, an exploratory study will be carried out on testing Marshall characteristics: Index or Retained Strength (IRS), Indirect Tensile Strength (ITS), Tensile Strength Ratio (TSR), Cantabro Loss (CL), and wheel tracking (WTM).

2. Research Method

This research uses a mixture of Superpave asphalt with two types of binding materials, namely Pen 60/70 and Starbit Pg-70, with Filler substitution using Fly Ash from PLTU Pacitan. The coarse aggregate, fine aggregate, and filler are from Clereng, while the Pen 60/70 bonding material is manufactured by PT. Pertamina

Table 1 Aggregate Physical Properties

Parameters	Spec.	Coarse	Fine
Specific Gravity	≥ 2,5	2,59	2,56
Water Absorption/porosity(%)	≤ 3	1,69	2,35
Adhesion of Aggregates-Bitumen Pen 60/70 (%)	≥ 95	96	-
Adhesion of Aggregates-Bitumen Starbit Pg-70 (%)	≥ 95	98	-
Abrasion (%)	≤ 40	12,5	-
Sand Equivalent (%)	≥ 50		91,9

Table 2 Bitumen Physical Properties

Parameters	Pen 60/70		Starbit Pg-70	
	Spec.	Result	Spec.	Result
Specific Gravity	≥ 1,0	1,02	≥ 1,0	1,03
Penetration (0,1 mm)	60-70	65,5	50-80	55,5
Ductility (cm)	≥ 100	165	≥ 50	130
Flash Point (°C)	≥ 232	270	≥ 225	315
Fire Point (°C)	≥ 232	285	≥ 225	325
Softening Point (°C)	≥ 48	48	≥ 54	55
TCE Solubility (%)	≥ 99	100	≥ 99	99,73
Penetration Index	-	-1,079	-	0,234

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and Starbit Pg-70 are produced by PT. Bintang Djaja. The initial stage was to test the characteristic properties of the aggregate materials, Pen 60/70 and Starbit Pg-70. Then, the optimum bitumen content (OBC) was determined for each type of binder and fly ash substitution. Furthermore, the Marshall test, Retained Strength (IRS) test, Indirect Tensile Strength (ITS), Tensile Strength Ratio (TSR), and Wheel Tracking (WTM) based on OBC conditions were carried out. The number of samples required to obtain OBC is 90, and 120 samples are required for testing samples with fly ash substitution at levels of 0%, 50%, and 100%.

3. Result and Discussion

3.1 Material Properties

Aggregate and bitumen test results can be seen in Table 1 and Table 2**.** Based on the results of bitumen testing and aggregate testing, it can be concluded that each test has met the 2018 Bina Marga requirements.

3.2 Optimum Bitumen Content

The ideal bitumen content for the Superpave mixture is determined based on parameters such as stability, marshall quantum (MQ), voids in mineral aggregate (VMA), voids filled with bitumen (VFWB), and voids in the total mix (VITM). Each parameter has minimum and maximum value requirements. Based on the Marshall characteristic test results on both binder and fly ash substitution types, the optimum bitumen content (OBC) was obtained as follows.

Based on Table 4, it can be seen that there is a difference in the optimum bitumen content (OBC) value, but it is not significant. However, with more fly ash substitutes, the need for OBC is also increasing, and the OBC needs for Starbit Pg-70 bitumen are greater than those for Pen 60/70 bitumen.

3.3 Marshall Characteristics of Superpave Mixture with Pen 60/70 and Starbit Pg-70 Binding Material in OBC Conditions.

A comparison of the test results of Marshall Standard at maximum bitumen content (OBC) conditions with Pen 60/70 and Starbit Pg-70 to the characteristics of Marshall Standard can be seen as follows:

3.3.1 Voids in Total Mix (VITM) and Voids Filled with Bitumen (VFWB)

The comparison among VITM and VFWB values in the Superpave mixture with Pen 60/70 and Starbit Pg-70 with fly ash substitution care is shown in Figure 1 and Figure 2.

Figure 1 shows that the VITM value decreases with increasing fly ash. This is because fly ash, as a filler substitute, can affect the volumetric characteristics of the mixture because it can fill the voids in the mixture. The amount of cavity content in the mixture shows the level of density and the stability, flexibility, and durability of the mixture. Mixtures with a greater void content tend to be more susceptible to water intrusion, resulting in a lower ability to maintain strength and durability. This is similar to research conducted by (Fauziah et al., 2012), which stated that fly ash could fill voids in the mixture so that the increased viscosity and cohesion of asphalt can have a significant effect in maintaining its stability against water disturbance so that the impermeability of the mixture and durability increase. Pavement mixtures using Pen 60/70 binder have lower VITM values compared to mixes using Starbit Pg-70. The small value of VITM in the Pen 60/70 binder mixture influences the

Table 3 Superpave Pavement Gradation Plan

Sieve Size			Specification		Percent Amount (%)	
			Min	Max	Passing	Retained
¾”	19	mm	100	100	100	0
½”	12,5	mm	90	100	97	3
3/8”	9,5	mm	78	90	86	14
No.8	2,36	mm	28	58	51	49
No.16	1,18	mm	14,57	33,21	32	68
No.30	0,60	mm	7,97	25	24	76
No.50	0,30	mm	4,56	17	16	84
No.200	0,075	mm	2	10	7	93
	Pan		0	0	0	100

Table 4 Optimum Bitumen Content

Substitution (%)	Substitution Filler (%)		Pen 60/70 (%)	Starbit Pg-70 (%)
	Aggregate	Fly Ash		
100	7	0	5,8	6
50	3,5	3,5	5,9	6,1
0	0	7	6	6,2

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high viscosity value of asphalt, so the performance in filling pavement cavities is better than Starbit Pg-70. This is similar to (Hadi et al., 2021), who concluded that pavements using Starbit bonding materials have a higher VITM value than a mixture of Pen 60/70 bonding materials.

The data presented in **Figure 2** indicates a rise in the VFWB value as the fly ash substitution increases. This can be attributed to the increased presence of bitumen, which fills the gaps between the aggregates in larger quantities. This is similar to research conducted by (Wahyuningsih, 2007), which confirmed that fly ash can fill larger cavities between grains. (Tahir et al., 2009) also stated that fly ash can absorb asphalt and fill more cavities. The mixture using Pen 60/70 had a relatively greater VFWB value than the Starbit Pg-70 binder. The high VFWB value in the mixture using Pen 60/70 bitumen is because the bitumen has a lower Penetration Index (PI) value of -1.079, while the PI value for Starbit is 0.234. This research is similar to (Yusuf et al., 2017), (Hadi et al., 2019), and (Hadi et al., 2021), which state that the high VFWB value in a mixture using Pen 60/70 binder indicates that the bitumen is very sensitive to changes in temperature, making it easier to fill the voids in the mixture.

3.3.2 Voids in Mineral Agregat (VMA) and Stability

The comparison between VMA and Stability values in the Superpave mixture with Pen 60/70 and Starbit Pg-70 with fly ash substitution care is shown in Figure 3 and Figure 4.

Figure 3 shows that the VMA value increases with increasing fly ash substitution. A high VMA value is an indicator of durability or influences the durability of the pavement mix. The trend of increasing the VMA value of the mixture is most likely due to the lack of mixture density due to decreased workability caused by the addition of fly ash. This is similar to research conducted by (Fauziah et al., 2012) and (Riyanto et al., 2020), which stated that increasing levels of fly ash were followed by increasing VMA values. When viewed from the type of bonding material used in the mixture, the mixture using Starbit Pg-70 binder has a VMA value that tends to be greater. This is the result of bitumen characteristics, specifically denoted as the penetration index value, which is part of the criteria indicating lower sensitivity to temperature when compared to the Pen 60/70 bonding material. The high VMA value for the Starbit binder is explained by (Nugroho et al., 2018). The asphalt mixture containing Starbit binder exhibits an elevated VMA value due to the lower penetration and higher softening point values. Consequently, filling the voids between aggregate grains becomes more challenging during the asphalt mixing process, resulting in reduced asphalt coverage on the aggregates.

Figure 4 shows that the stability value of the mixture made with Starbit Pg-70 binder is significantly higher when compared to the mixture made with Pen 60/70 binder. Starbit Pg-70 bitumen has also proven to be better in terms of stability because polymer-modified bitumen is more resistant to deformation, especially at high temperatures. This opinion is similar to research conducted by (Asmael et al., 2018), which states that using polymer bitumen will increase stability. The stability value obtained in this study follows the 2018 Bina Marga requirements, namely > 800 kg. In addition, the stability value and the increase in fly ash substitution tend to increase. This is because the substitution of fly ash filler content can increase the viscosity and cohesion of bitumen, so the greater the substitution of fly ash, the greater the viscosity and cohesion of bitumen. As concluded by Brien (1978) and Brown (1990), an increase in viscosity (a decrease in penetration value) will lead to an increase in the resistance of the mixture to deformation. According to (Fauziah et al., 2012),

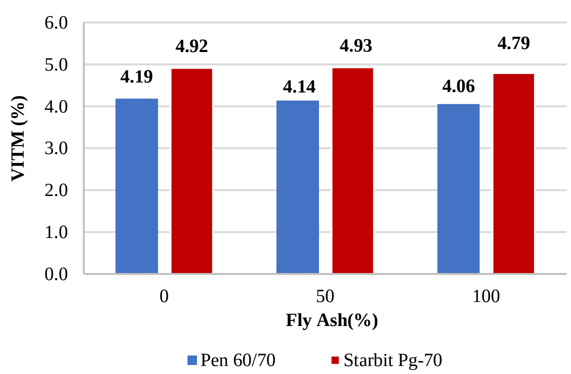

Fig 1. Comparison of VITM Values with Pen 60/70 and Starbit Pg-70 Binding Materials with Fly Ash Substitution

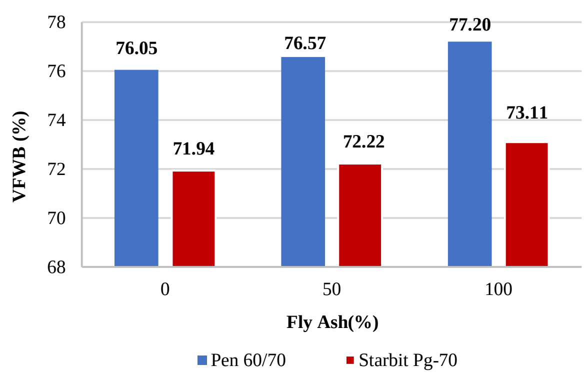

Fig 2. Comparison of VFWB Values with Pen 60/70 and Starbit Pg-70 Binding Materials with Fly Ash Substitution

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Chemically, fly ash has pozzolanic properties that contain silica, iron oxide, aluminum oxide, calcium oxide, magnesium oxide, and sulfate, which, when added to bitumen (C4H10), will form a compound reaction that makes the mixture stiff and hard. This is also following (Hainin et al., 2014), which concluded that using fly ash can increase the stability value of the mixture.

3.3.3 Flow and Density

The comparison between Flow and Density values in the Superpave mixture with Pen 60/70 and Starbit Pg-70 with fly ash substitution care is shown in Figure 5 and Figure 6.

According to the information in **Figure 5**, it is apparent that the flow value decreases as the substitution of fly ash increases. Fly ash substitution resulted in increased asphalt viscosity. According to (Fauziah et al., 2012), the main content of fly ash, which consists of silicon, iron oxide, and aluminum oxide, added to asphalt will react and form compounds that make the mixture hard and stiff, as evidenced by the decreasing flow value of the mixture. In addition, the mixture using Pen 60/70 tends to be greater than that using Starbit Pg-70 binder. The difference in flow values for the two bonding materials is due to differences in the softening point values, namely Pen 60/70 bitumen at 48°C and Starbit Pg-70 at 55°C. Based on the softening point value, it was found that Pen 60/70 bitumen has a greater temperature sensitivity than Starbit Pg-70 bitumen. This is similar to research conducted by (Nugroho et al., 2018) and (Hadi et al., 2021), which indicates that Pen 60/70 bitumen is more temperature-sensitive than Starbit E-55 bitumen. Moreover, the viscosity of Pen 60/70 is greater than the value of Starbit bitumen. Thus, Pen 60/70 bitumen flows more easily in the cavity of the mixture.

Figure 6 shows that the difference in the density value of the mixture is not significant due to fly ash, but the density value of the mixture using Pen 60/70 binder. The high-density value in the mixture using Pen 60/70 binder proves that bitumen has more liquid properties, so the use of this bitumen will have an impact in the form of

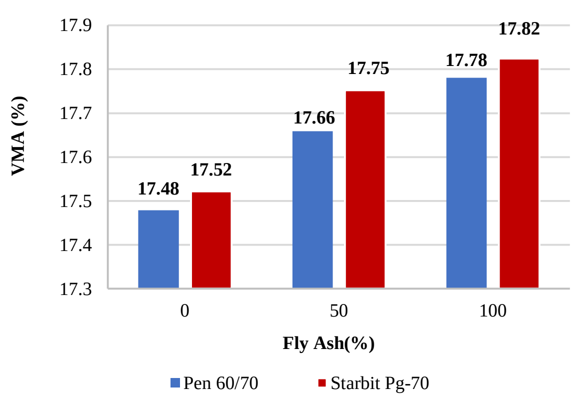

Fig 3. Comparison of VMA Values with Pen 60/70 and Starbit Pg-70 Binding Materials with Fly Ash Substitution

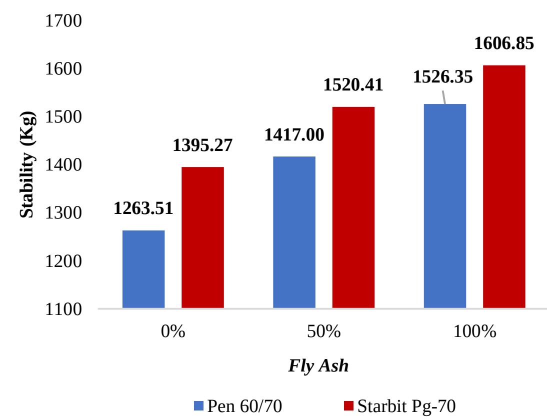

Fig 4. Comparison of Stability Values with Pen 60/70 and Starbit Pg-70 Binding Materials with Fly Ash Substitution

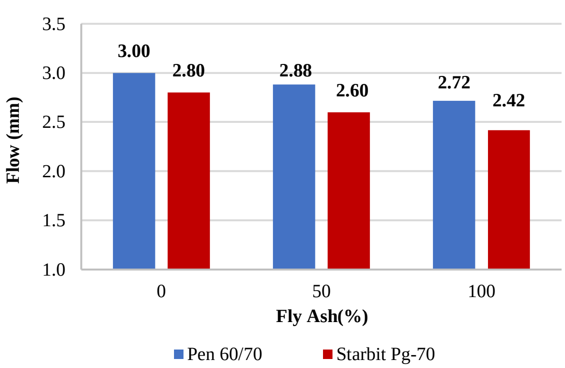

Fig 5. Comparison of Flow Values with Pen 60/70 and Starbit Pg-70 Binding Materials with Fly Ash Substitution

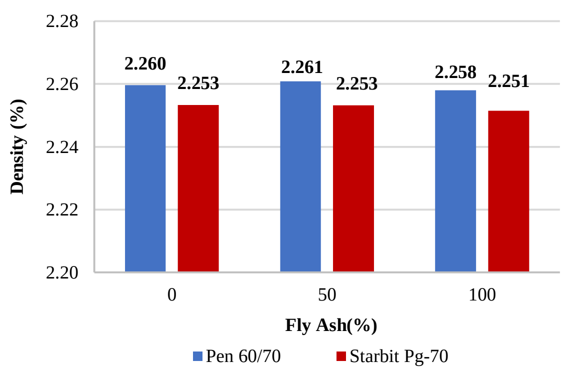

Fig 6. Comparison of Density Values with Pen 60/70 and Starbit Pg-70 Binding Materials with Fly Ash Substitution

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a denser pavement. This is also in line with the high VFWB value and low VITM value in the mixture made of 60/70 Pen tie. According to (Nugroho et al., 2018), the properties of Pen 60/70 bitumen, which melts quickly, are due to the relatively greater viscosity value of the bitumen. This is similar to research conducted by (Yulienda, 2017), which stated that the density value of the Pen 60/70 adhesive mixture was significantly higher when compared to the Starbit E-55 bonded mixture due to the properties of Pen 60/70 bitumen liquids more easily.

3.4 Comparison of Index Tensile Strength, Index Retained Strength, and Tensile Strength Ratio Values on OBC with Pen 60/70 and Starbit Pg-70 Bonding Materials with Fly Ash Substitution

The comparison between ITS, IRS, and TSR values in the Superpave mixture with Pen 60/70 and Starbit Pg-70 with fly ash substitution is shown in Figure 7 and Figure 8.

Figure 7 shows that the mixture using a Starbit Pg-70 binder has a greater ITS value than the mixture using a Pen 60/70. The high ITS value in the mixture using Starbit Pg-70 bitumen can allow the pavement layer to resist tensile strength caused by vehicle loads, which affects its resistance to damage in the form of rutting or permanent deformation. This is due to the nature of Starbit bitumen, which is more flexible in resisting deformation and shear at relatively high temperatures but stiff at low temperatures. This is in line with (Hadi et al., 2021), which concluded that a pavement mixture using Starbit binder will have properties that are more resistant to immersion than a pavement mix using Pen 60/70 binder. In addition, adding fly ash can also increase the ITS value; the ITS value increases in line with the fly ash substitution. This is in line with research conducted by (Fauziah et al., 2012), which stated that fly ash makes the mixture more able to maintain its strength. Fly ash results in an increase in the viscosity and cohesion of asphalt so that the impermeability and durability of the mixture increase. Fly ash can also fill voids in the mixture, so the increased viscosity and cohesion of asphalt can significantly affect maintaining its stability against water disturbance.

Figure 8 shows that the IRS value of the mixture with the Starbit Pg-70 binder is higher than that of the Pen 60/70 binder mixture but is insignificant. This proves that the mixture using Starbit Pg-70 bitumen can withstand extreme temperatures compared to mixtures made from bonding Pen 60/70. In simpler terms, a high IRS for the Starbit Pg-70 bonding material suggests that it significantly contributes to the durability of pavement by maintaining its ability to withstand tension when immersed or simulated in certain conditions. The high IRS value indicates that using the Starbit Pg-70 binder will glue the aggregate together so that the mixture becomes stronger against tensile forces for the specified duration of the immersion process. Using fly ash as a filler substitute can also increase the IRS value. These results indicate that adding fly ash can help the mixture maintain its strength. According to (Fauziah et al., 2012), fly ash increases the viscosity and cohesion of asphalt, so the impermeability and durability of the mixture increase.

Figure 9 shows that the TSR value correlated with the addition of fly ash substitution, and besides that, the TSR value of the mixture using the Starbit Pg-70 binder is greater than that of the mixture using the Pen 60/70 binder. This is because Starbit Pg-70 bitumen is a modified bitumen, so it is more resistant to high or extreme temperatures. The TSR value indicates that the mixture using a Starbit Pg-70 binder can affect pavement durability by maintaining its simulated tensile strength in immersion. This is in line with research conducted by

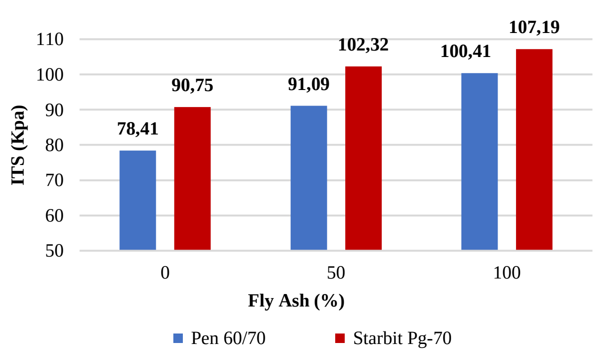

Fig 7. Comparison of ITS Values with Pen 60/70 and Starbit Pg-70 Binding Materials with Fly Ash Substitution

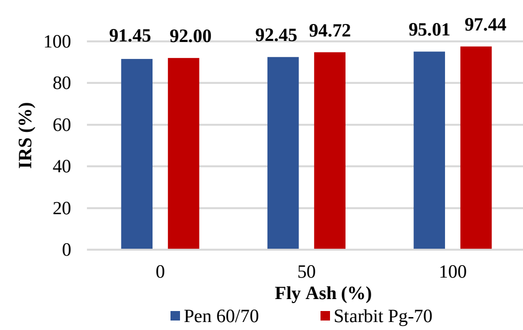

Fig 8. Comparison of IRS Values with Pen 60/70 and Starbit Pg-70 Binding Materials with Fly Ash Substitution

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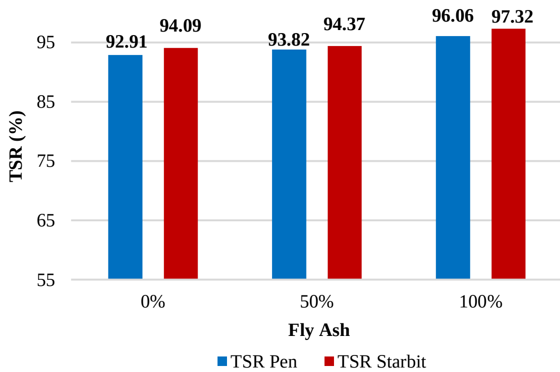

Fig 9. Comparison of ITS Values with Pen 60/70 and Starbit Pg-70 Binding Materials with Fly Ash Substitution

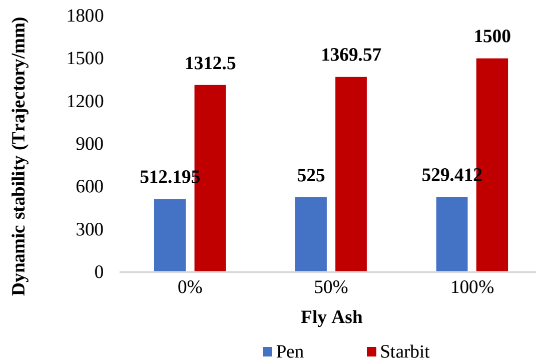

Fig. 10 Comparison of Dynamic Stability Values in OBC with Fly Ash Substitution

(Hadi et al., 2021), which states that the considerable TSR value indicates that the use of Starbit Pg-70 bitumen can glue the aggregate so that the mixture becomes stronger against tensile forces during the soaking process. Thus, adding in fly ash can also increase the TSR value; the TSR value increases in line with the fly ash substitution. This is in line with research conducted by (Fauziah et al., 2012), which stated that fly ash could fill voids in the mixture so that the increased viscosity and cohesion of asphalt can have a significant effect in maintaining its stability against water disturbance so that the impermeability of the mixture and durability increase.

3.8 Characteristics of the Wheel Tracking mixture of Superpave with Ikat Pen 60/70 and Starbit Pg-70 with Fly Ash Substitution

A comparison of the wheel tracking test results on the OBC Pen 60/70 binder and Starbit Pg-70 binder can be seen in Figures 10 and 11 below.

Based on **Figures 10 and 11**, it can be explained that the results of the wheel tracking machine test at a temperature of 60° C with fly ash substitution as a filler replacement material experienced an increase in the dynamic stability value as the fly ash substitution content increased. Dynamic stability is a parameter that shows how many passes are needed to produce a groove depth in mm. The presence of fly ash substitution can increase the dynamic stability value and reduce the deformation speed value. This shows that fly ash is able to increase the dynamic stability value and reduce the deformation effect compared to stone ash. This is because fly ash can fill the voids in the mixture, thereby causing interlock better and decreasing the effects of deformation. This result is similar to research by (Mutohar, 2002), which states that mixtures using fly ash have smaller deformation speed values and better dynamic stability values when compared to stone ash filler. A low deformation value indicates that the mixture tends to be rigid. Conversely, a high deformation speed indicates that the mixture is plastic or flexible and easily deforms when subjected to traffic loads.

4. Conclusion

The use of Starbit Pg-70 binder has been proven to produce much better mechanical properties, such as much higher stability, than mixtures using Pen 60/70 binder. In addition, Fly Ash is also able to increase the viscosity and cohesion of asphalt, so that asphalt is able to have a significant effect on maintaining its stability against water disturbance. On the other hand, the use of a Starbit Pg-70 binder in bitumen concrete tends to have better durability performance than that of mixtures using a Pen 60/70 binder. The residual strength index of the mixture with Starbit Pg-70 bonding material was higher than that of the Pen 60/70 bonding mixture, and the mixture using the Starbit Pg-70 bonding agent was more durable than the Pen 60/70 bonding mixture. The use of Fly Ash as a filler substitution can fill voids in the mixture so that the increase in asphalt viscosity and cohesion can significantly affect maintaining its stability against water disturbance, resulting in increased impermeability of the mixture and durability. Fly ash is also able to fill cavities, thus creating better interlocking between materials so as to maintain the initial conditions against the effects of impact.

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