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Indirect Tensile Fatigue Test (ITFT) Analysis of Asbuton Mixture with Used Oil Additives and HDPE

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Abstract: This study aims to assess the impact of the use of used oil and High Density Polyethylene (HDPE) plastic as additives in asphalt mixtures modified with Asbuton on fatigue resistance in AC-BC mixtures. This mixture is designed with an optimal asphalt content of 6.0% and combined with variations in the proportion of modified Asbuton asphalt and oil asphalt. Testing was carried out using the Indirect Tensile Fatigue Test (ITFT) method at a pressure of 500 kPa and at a temperature of 20 degrees Celsius to evaluate fatigue performance due to repeated loads. The results showed that increasing the proportion of modified asphalt containing Asbuton, used oil, and HDPE resulted in a significant increasing trend in the fatigue life of the tested specimens. These findings indicate that asphalt modification with a combination of these waste materials can increase the flexibility and resistance of the mixture to repeated loads. This study contributes to the development of more environmentally friendly road pavement materials with better performance.

Keywords: AC-BC; Asbuton; HDPE; ITFT; Used oil

Introduction

Indonesia has a lot of natural asphalt resources, especially on Buton Island. Buton asphalt, also called asbuton, is one of the biggest natural bitumen deposits in the world. It has a high amount of active asphalt, which makes it a good option to partly replace petroleum-based bitumen in road mixtures (Karyawan et al., 2021; Sihombing et al., 2021). Studies have shown that using asbuton that has been extracted or modified can improve how well asphalt resists aging and help keep the mix stable (Gusty, 2024; Karyawan et al., 2022, 2023; Sentosa et al., 2019).

But using asbuton directly has some challenges. It is very stiff and doesn't stick well at normal temperatures, which can cause it to become brittle and crack early, especially with heavy traffic (Djakfar et al., 2022; Lee & Le, 2023). To fix these issues, new ways have been developed to modify asbuton using waste materials like used oil (WEO) and high-density polyethylene (HDPE) (Aljarmouzi & Dong, 2022; Ghani et al., 2022).

WEO has light hydrocarbon parts that are similar to maltenes found in bitumen. These parts work as a rejuvenator, which helps to lower the stickiness of the binder, makes the mixture more flexible, and improves how well it can be mixed and shaped (Cheng et al., 2022; Peng et al., 2020; Sun et al., 2019). At the same time, HDPE acts as a strengthening material in the asphalt mix, helping to increase its stiffness, make it more resistant to rutting, and improve its ability to handle heat. This makes HDPE a good choice for areas with hot climates like Indonesia (Putri & Vasilsa, 2019; Langa et al., 2023; Nawir & Mansur, 2022; Piromanski et al., 2020). Also, using these materials helps make construction more sustainable (Aljarmouzi & Dong, 2022; White, 2020).

Although there have been many studies on the individual effects of WEO and HDPE, how they work together in asphalt mixtures especially when combined with asbuton is not well understood. This is especially true when it comes to how the mix handles repeated stress, which is a key factor in how long a road last. In Indonesia, most tests for asphalt mixtures still use the

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Marshall method, which checks early strength and density. But this method doesn't show how well the mix holds up under constant pressure, which is a major reason roads fail over time (Ameri & Shiraz, 2024; Shang et al., 2024).

To fix this, the Indirect Tensile Fatigue Test (ITFT) is a better way to check how long a mix can last, how much it can bend without breaking, and how it handles repeated stress (Bich, 2024; Brovelli et al., 2014; Cheng et al., 2022; Li, 2013). Using ITFT is important for testing how well modified asphalt mixtures perform over time. With this background, this study looks at how well AC-BC asphalt mixtures work when they are mixed with 60/70 penetration asphalt, asbuton, WEO, and HDPE. The study uses the ITFT method to check the mix's ability to handle fatigue. The results should help create better and more eco-friendly road materials by using waste-based additives.

Method

This research was carried out in the Transportation Laboratory of the Department of Civil Engineering, Faculty of Engineering, University of Mataram, West Nusa Tenggara, and the Highway Laboratory of the Civil Engineering Study Program, Udayana University, Bali.

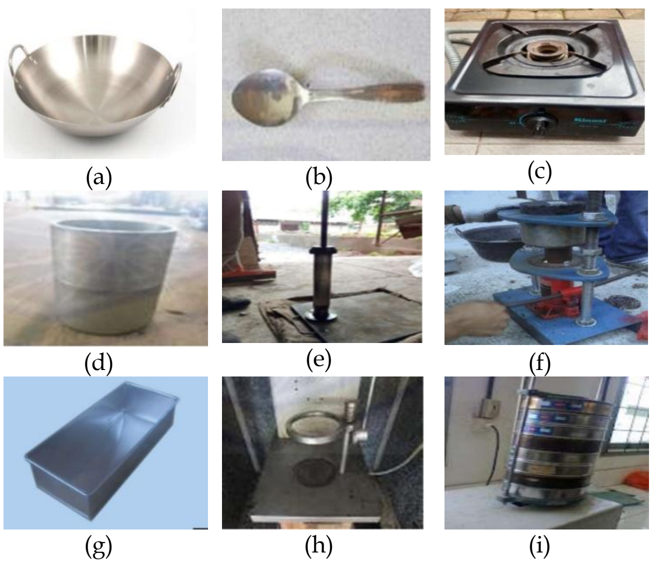

Figure 1. Equipment for making test specimens: (a) Cauldrons, (b) Spoons, (c) Stoves, (d) Test specimen molds, (e) Fist rods, (f) Ejectors, (g) Zinc cans, (h) Compactor substrates, (i) Aggregate sieve

There are two types of data used in this study, namely primary data and secondary data. Primary data is data collected directly through a series of self-conducted experimental activities with reference to manual instructions. Secondary data is data obtained indirectly or obtained from previous research that uses the same material and is still interrelated or sustainable, which in this study uses data from previous research. The equipment used is as shown in Figure 1.

Figure 2. Dynapave UTM 30

Figure 2 is the tool used for the Indirect Tensile Fatigue Test (ITFT) test. The materials used in this study are as follows:

1) Asphalt oil Penetration 60/70
2) Asbuton extraction from PT. The Formation of the Greek Culture
3) Used oil
4) HDPE plastic waste
5) Coarse and Fine Aggregate Material from PT. Sinar Bali Pringgabaya-East Lombok
6) Filler with Semen

Test Piece Manufacturing and Testing

At this stage, all materials have been prepared according to the needs of the research, the fabricated materials that have been equipped with documents in the form of test result certificates are no longer carried out property tests, the researcher only uses existing data, while for materials such as asphalt and aggregates, tests are carried out according to the specifications of the 2018 General Highways (Kementerian Pekerjaan Umum dan Perumahan Rakyat & Direktorat Jenderal Bina Marga, 2020).

Asphalt testing and inspection includes: daktalicity test, penetration, flash point, soft spot, specific gravity, oil weight loss. The test results cite existing data from previous research.

For coarse aggregate, fine aggregate and filler testing includes: aggregate wear testing, bulk specific gravity, surface dry saturated specific gravity, pseudo-specific gravity, effective specific gravity, water absorption, and gradation. The results of this property test are taken from secondary data, namely from the results of previous research.

At this stage, all property test results that have met the general specification standards of Bina Marga 2018 are used as a reference to make a mixed design, this mixed design also takes data from secondary data from the research results (Karyawan et al., 2024) This mix design is taken from the results of the value with the best K.A.O, which is as much as 6% and the best marshall value using a mixture of 50% oil asphalt and 50% modified asphalt. Therefore, the composition of the mixture is tried as follows.

Table 1. Composition of test specimen mixture I

Material	Sum (%)	Details
Asphalt (modified asphalt + oil asphalt)	6	40% Modified asphalt (MO). 60% Asphalt oil (MI)
Coarse aggregate	42	100% Natural aggregate
Fine aggregate	46	100% Natural aggregate
Filler	6	100% Natural aggregate

Table 2. Mixed composition of test specimen II

Material	Sum (%)	Details
Asphalt (modified asphalt + oil asphalt)	6	50% Modified asphalt (MO). 50% Asphalt oil (MI)
Coarse aggregate	42	100% Natural aggregate
Fine aggregate	46	100% Natural aggregate
Filler	6	100% Natural aggregate

Table 3. Composition of test specimen mixture III

Material	Sum (%)	Details
Asphalt (modified asphalt + oil asphalt)	6	60% Modified asphalt (MO). 40% Asphalt oil (MI)
Coarse aggregate	42	100% Natural aggregate
Fine aggregate	46	100% Natural aggregate
Filler	6	100% Natural aggregate

Before the manufacture of the test piece, the first thing done is to make a modified asphalt mixture. The manufacture of modified asphalt is carried out by the hot asphalt-plastic mixture method (Afriyanto et al., 2019). Asphalt and plastic are heated in different containers. After both have melted, the asphalt is poured into a plastic container that has melted. Then stirring is carried out during mixing until the modified asphalt becomes homogeneous and the mixing temperature when a homogeneous mixture is obtained is recorded. Likewise, used oil is added when the asphalt melts.

The comparison of mixing asphalt and modified materials (waste oil and HDPE) used was 100 grams of asphalt extracted from asbutone plus 5 grams of used oil and 6 grams of HDPE plastic After the modified asphalt mixture is completed, the test object begins to be made.

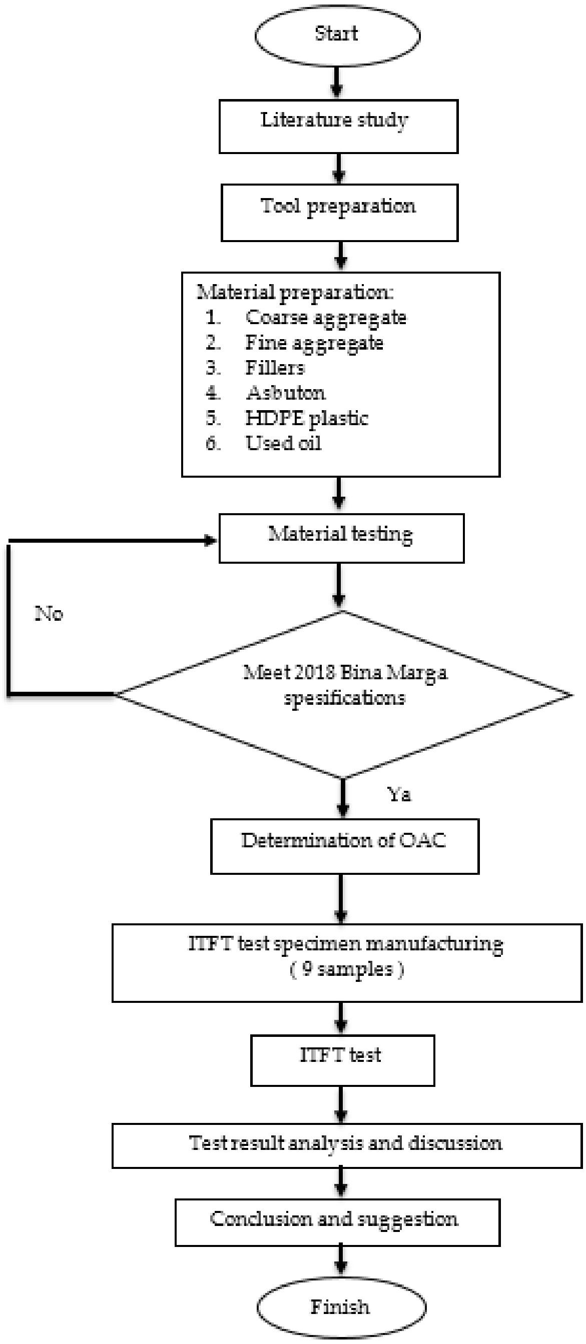

Figure 3. Flow chart

For this ITFT test, we used test specimens that were compacted according to the Marshall test, because there was no rotary compaction. The stages of making the test specimen are as follows:

1) Weigh HDPE plastic and extract asbuton, then heat both in different pans until they melted.
2) Mix the heated extraction asbuton with the melted HDPE plastic, stir until homogeneous, then add the used oil according to the measurement. Mix the three ingredients until homogeneous, after looking

homogeneous, this mixture is cooled until room temperature.

3) Heat coarse aggregates, fine aggregates and fillers according to the available amount, heated to 170ºC.
4) Mix asphalt oli penetration 60/70 with modified asphalt according to the dosage in composition I (40% modified aspal and 60% oil aspal). Composition II (50% modified aspal and 50% oil asphalt) and composition III (60% modified aspal and 40% oil aspal) stir until it looks homogeneous at a temperature of 140–160º C.
5) Put the coarse aggregate, fine aggregate and filler into the oil asphalt and modified asphalt that has been mixed, stirring until homogeneously mixed at a temperature of 140–160º C.
6) For the mixture, 3 test pieces are made for each composition, so the total test pieces are 9 pieces.
7) Once the mixture looks homogeneous, place it in the test specimen mold, by coating it with the paper bottom of the mold.
8) Pierce the mixture with a spatula inside the mold 25 times, then the top layer of the mold is coated with paper, then the test specimen is mashed 2 x 75 on the top and bottom of the mold.
9) After finishing the mash, the test specimen is removed from the mold using an ejector device.
10) After that, the test specimen is cooled for 24 hours and each sample is named.

Based on the Fatigue test procedure manual for road pavement samples using the Dynapave Universal Testing Machine (UTM) prepared by I Nyoman Arya Thanaya, the Civil Engineering study program, Faculty of Engineering, Udayana University in 2017, the following is the method of Fatigue testing used.
The test procedure is carried out as follows:

1. Suitable Transducer set on IMAC channel
2. Calculate the load to get the desired stress. For this test, we use 500 Kpa for the load.
3. Select the UTS013, Indirect Tensile Fatigue (ITFT) Test menu. Data Input and Set Up Parameters. Select axial loading, Haversine (dynamic).
4. Seting Load Actuator, Tranducer Level dan Start Level
5. Notes for ITFT
   a) The load / stress applied adjusts to the strength of the sample, so it needs to be tested with a certain level of load/stress.
   b) Ideally, the load/stress applied repeatedly until it collapses, a certain amount that can give the number of repeated loads until it collapses (failure) between 10^3 – 10^6. If the sample is not strong, this should be adjusted.
   c) If the load is too low (it can occur on a strong sample), so that it does not exert strain on the sample, this will cause the machine to stop with a message on the monitor: 'Invalid floating point operation'. For this reason, the load needs to be increased.
   d) The test results are in the form of pdf or nadi csv files that can be opened and processed using excel (Thanaya, 2017).

Result and Discussion

Asphalt, Aggregate and Filler Test Results

The 60/70 penetration asphalt test aims to find out the characteristics of asphalt as a binding agent in the mixture. This study uses asphalt from PT. Kresna Karya, Pringgabaya District, East Lombok Regency. This test refers to the 2018 General Specification of Bina Marga Revision 2 which consists of several parameters in the study. For test results, see Table 4.

Table 4. 60/70 penetration asphalt test results

Types of Testing	Asphalt Pen 60/70	Specifications
Penetration at 25ºC (0.1 mm)	63.5	60–70
Soft Spot ºC	53	≥ 48
Flash Point ºC	300	≥ 232
Ductility at 25ºC (cm)	149.1	≥ 100
Specific Gravity	1.04	≥ 1.0
Oil Weight Loss (%)	0.29	≤ 0.8

Based on the test results contained in Table 4, all test results meet the standards of the 2018 General Specification of Bina Marga Revision 2 (2020). So that the asphalt can be used in this study as a binding material in the pavement mixture.

Testing of modified asphalt from asphalt extraction of Asbuton, 5% waste oil and 6% HDPE aims to find out the characteristics of asphalt as a binding agent in the mixture. This study uses asphalt from PT. Sustainable Nature Performance Gresik, East Java. This test refers to the General Specification of Highways which consists of several parameters in the study. For test results, see Table 5.

Table 5. Modified asphalt test results

Types of Testing	Modified Asphalt	Specifications
Penetration at 25ºC (0.1 mm)	63.1	50–60
Soft Spot ºC	96	≥ 50
Flash Point ºC	232	≥ 232
Ductility at 25ºC (cm)	9.55	≥ 100
Specific Gravity	1.498	≥ 1,0
Weight Loss (%)	0.045	≤ 0.8

Based on the test results contained in Table 5, the test results obtained penetration, soft spots, flash points, specific gravity, and weight loss meet the standards of the 2018 General Specification of Bina Marga Revision 2 (2020), only the ductility test does not meet the standards of the General Specification of Bina Marga 2018 Revision 2 (2020).

The purpose of testing aggregates and fillers is to determine whether the characteristics of aggregates and fillers meet the General Specifications of Bina Marga 2018 Revision 2 (2020) or not. The aggregate used consists of coarse and fine aggregates derived from PT. Sinar Bali Binakarya, Pringgbaya, East Lombok Regency. As for the filler, it uses Bosowa brand portland cement. For test results, see Table 6.

Table 6. Aggregate and filler test results

Aggregate testing	Results	Specifications
Coarse aggregate		
Bulk Specific Gravity	2.73	
Surface Dry Saturated Specific Gravity	2.78	≥ 2.5
Pseudo-Gravity	2.88	
Effective Specific Gravity	2.8	
Keausan Impact (%)	20	< 30
Absorption (%)	0.02	< 3
Fine aggregate		
Bulk Specific Gravity	2.75	
Surface Dry Saturated Specific Gravity	2.83	≥ 2.5
Pseudo-Gravity	2.98	
Effective Specific Gravity	2.87	
Absorption (%)	0.03	< 3
Filler (semen portland bosowa)		
Bulk Specific Gravity	2.3	
Surface Dry Saturated Specific Gravity	2.3	≥ 2.5
Pseudo-Gravity	2.31	
Effective Specific Gravity	2.3	
Absorption (%)	0.06	< 3

Based on the test results in Table 6, all test results of coarse aggregates, fine aggregates, and fillers have met the standards of the 2018 Bina Marga General Specification Revision 2 (2020). So that aggregates and fillers can be used as pavement mixing materials in this study.

Determination of Mixed Warranty of Test Specimen and OAC

The purpose of this determination is to determine the characteristics of the AC – BC laston using the middle limit of the aggregate gradation according to the standards of the General Specification of Bina Marga 2018 Revision 2 (2020).

Table 7. Gradation of aggregates in mixtures

No	Sieve size (mm)	AC - BC	Middle Value	Pass Percentage (%)	Percentage Held (%)
1"	25	100	100	100	0
3/4"	19	90–100	95	95	5
1/2"	12.5	75–90	83	83	12
3/8"	9.5	66–82	74	74	9
No.4	4.75	46–64	55	55	19
No.8	2.36	30–49	40	40	15
No.16	1.18	18–38	28	28	12
No.30	0.6	12–28	20	20	8
No.50	0.3	7–20	14	14	6
No.100	0.15	5–13	9	9	5
No.200	0.075	4–8	6	6	3
Filler					6
Total					100

From Table 7. the aggregate gradation for laston AC – BC is obtained in Figure 4.

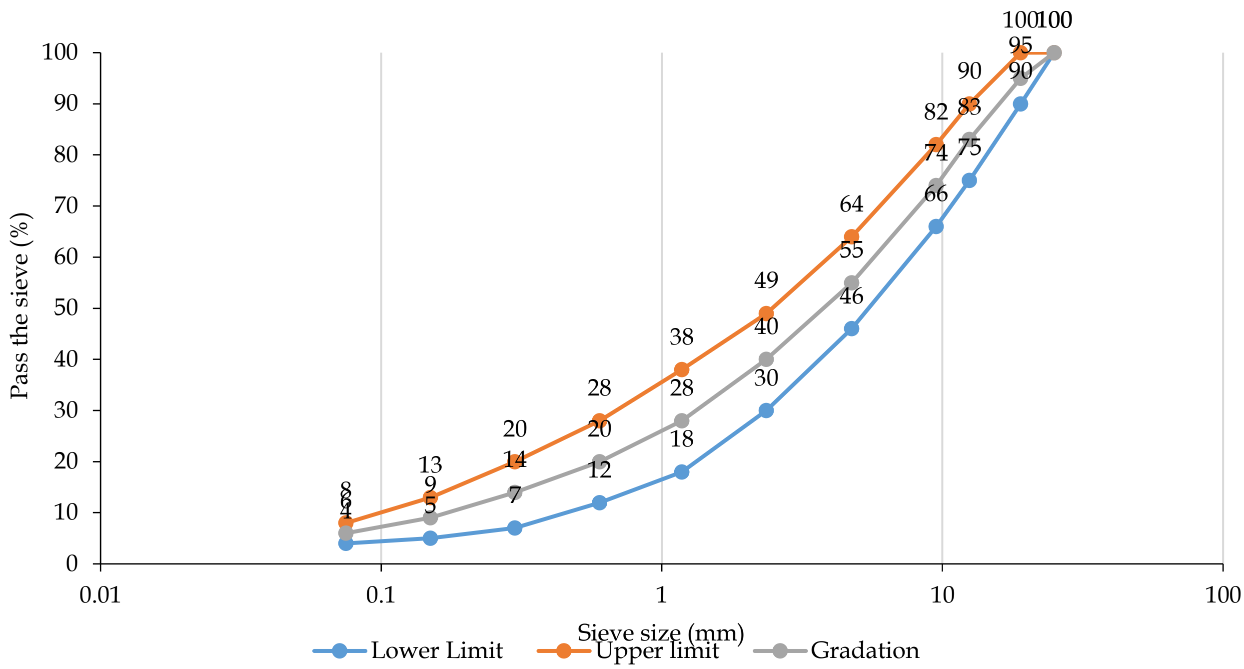

Figure 4. Aggregate gradient graph for Laston AC – BC

In Table 7, the proportional value of each aggregate fraction and filler is known. For the percent of the coarse aggregate expressed in the formula as (%CA), the percent of the fine aggregate with the symbol (%FA), the percent of the filler with the symbol (%FF), and 0.75 is the constant (K) for the laston. So that the value of the planned asphalt content (Pb) can be determined as follows:

$$Pb = 0.035(\%CA) + 0.45(\%FA) + 0.18(\%FF) + K$$
$$Pb = 0.035(45) + 0.045(49) + (0.18(6) + 0.75$$
$$Pb = 5.6\% \approx 6\% \text{ (rounded result)}$$

The value of Pb = 6% was obtained from the calculation results, so that for the value of other variations it could be determined, namely Pb-1 = 5%, Pb-0.5 = 5.5%, Pb = 6%, Pb+0.5 = 6.5%, and Pb+1 = 7%. After determining the value of each variation in the planned asphalt content (Pb), the next stage calculates the optimal asphalt content value (OAC).

The optimal asphalt content is determined using the Bina Marga standard which must meet 6 test parameters, namely: stability, flow, MQ, VMA, VIM, and VFB. In this test, 5 variations of asphalt content were used to obtain the optimum asphalt content (KAO), namely 5, 5.5, 6, 6.5, and 7%.

Stability

Stability values can be influenced by cohesion, penetration, asphalt content, internal friction, interlocking properties of aggregate particles, and aggregate gradation. The results of the mechanical stability calculations are shown in Table 8.

Table 8. Stability calculation result

Asphalt content (%)	Stability (kg)	Specification
5.0	2305.146	
5.5	2060.109	
6.0	1672.599	≥ 800 kg
6.5	1519.655	
7.0	1368.206	

From Table 8, a graph of the relationship between asphalt content and stability is obtained in Figure 5.

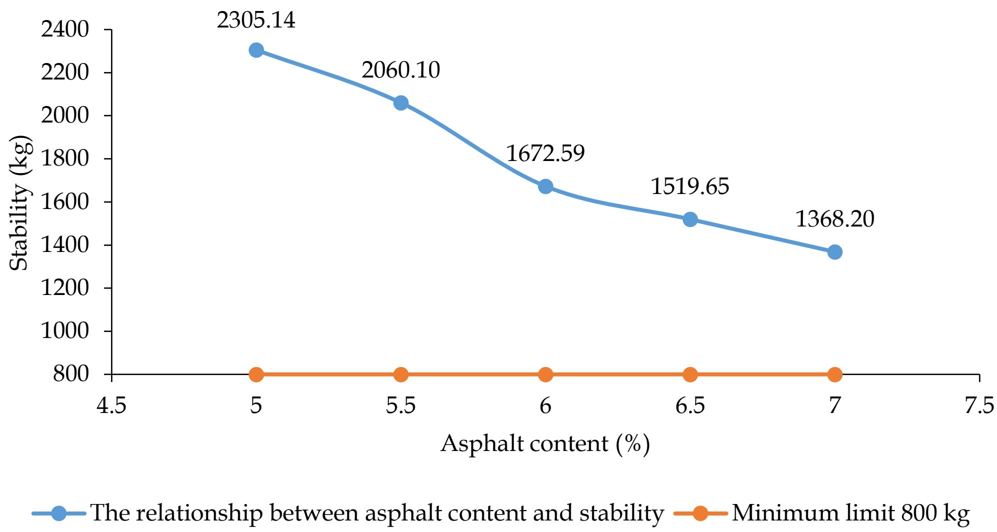

Figure 5. Graph of the relationship between asphalt content and stability

Based on Figure 5, all stability values for each asphalt content used meet the standards of the 2018 General Highways Specifications Revision 2 (2020), which is above 800 kg. The higher the asphalt content used, the lower the stability value. This is because the asphalt cannot properly coat the aggregate. The higher the asphalt content, the less able the cavities in the mixture are to absorb, resulting in thickening of the asphalt blanket and the layer easily shifting when loaded (Muharraran et al., 2024).

Flow

Flow is the extent of plastic deformation of a test object due to loading applied to the point of failure. Flow values can be influenced by aggregate gradation and asphalt content. The results of the mechanical flow calculations can be seen in Table 9.

Table 9. Flow calculation results

Asphalt Content (%)	Flow (mm)	Specification (mm)
5.0	1.990	
5.5	1.997	
6.0	3.747	2–4
6.5	3.910	
7.0	3.993	

From Table 9, a graph of the relationship between asphalt content and flow is obtained in Figure 6.

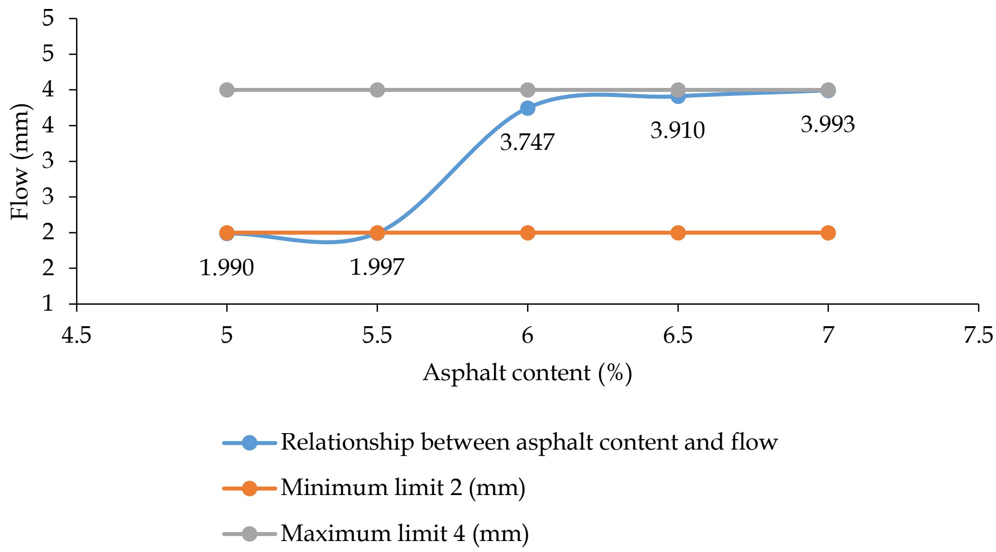

Figure 6. Graph of the relationship between asphalt content and flow

Based on Figure 6, the flow value meets the standards of the 2018 General Bina Marga Specifications Revision 2 (2020), namely at 6% asphalt content of 3.747 mm, 6.6% asphalt content of 3.910 mm, and 7% asphalt content of 3.993 mm. Meanwhile, at 5 and 5.5% asphalt content, it does not meet the specification standards used. The higher the asphalt content used, the higher the flow value. This occurs because the higher the asphalt content, the more voids are filled and the volume of voids in the mixture decreases. So that the aggregate is not well covered by asphalt and reduces the binding capacity of the asphalt. In addition, the higher the flow value, the more plastic the asphalt is and easily experiences changes in shape such as waves (washboarding) and grooves (rutting) (Sumiati et al., 2019).

Marshall Quotien (MQ)

The Marshall Quotient (MQ) is the ratio of stability to flow. The Marshall Quotient (MQ) value is influenced by stability, flow, penetration, viscosity, asphalt content, and aggregate gradation. The results of the mechanical Marshall Quotient (MQ) calculation can be seen in Table 10. From Table 10, a graph of the relationship between asphalt content and Marshall Quotient (MQ) is obtained in Figure 7.

Table 10. Results of Marshall Quotient (MQ) calculation

Asphalt content (%)	MQ (Kg/mm)	Specification (Kg/mm)
5.0	1338.539	
5.5	1152.677	
6.0	459.829	≥ 250
6.5	394.809	
7.0	341.301	

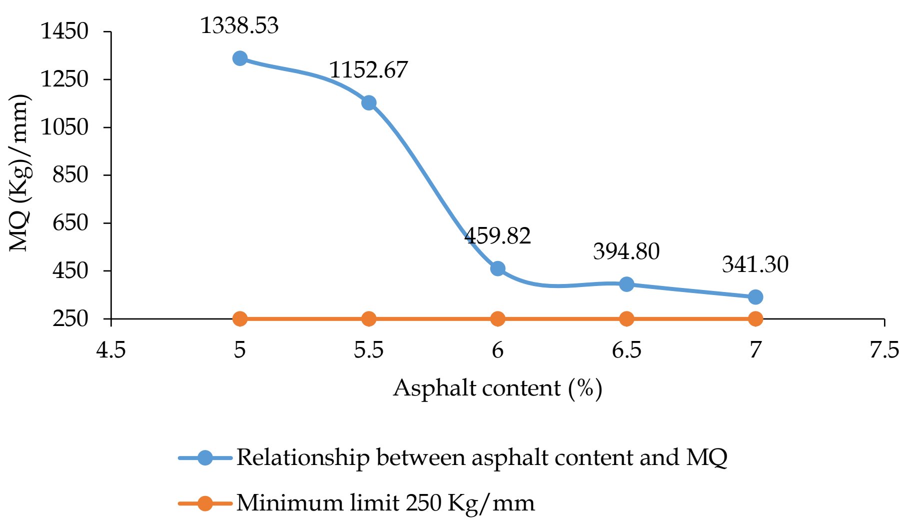

Figure 7. Graph of the relationship between asphalt content and Marshall Quotien (MQ)

Based on Figure 7, all Marshall Quotient (MQ) values meet the standards of the 2018 General Highways Specifications Revision 2 (2020), which is above 250 kg/mm. The higher the asphalt content used, the lower the Marshall Quotient (MQ). This is due to the decreasing stability with increasing asphalt content and increasing flow value. A lower Marshall Quotient (MQ) value indicates a plastic mixture (Khairani et al., 2018; Maghfirah et al., 2024).

Void in Mineral Aggregate (VMA)

Void in mineral aggregate (VMA) is the air cavity between aggregate grains in a compacted asphalt mixture and is expressed as a percentage. The void in mineral aggregate (VMA) value is influenced by asphalt content, aggregate gradation, number of impacts, and compaction temperature. The results of the calculation of the volumetric void in mineral aggregate (VMA) value can be seen in Table 11.

Table 11. Results of Void in Mineral Aggregate (VMA) calculation

Asphalt content (%)	VMA (%)	Spesification (%)
5.0	14.445	
5.5	14.660	
6.0	14.774	≥ 14
6.5	14.789	
7.0	14.908	

From Table 11, a graph of the relationship between asphalt content and Void in Mineral Aggregate (VMA) is obtained in Figure 8.

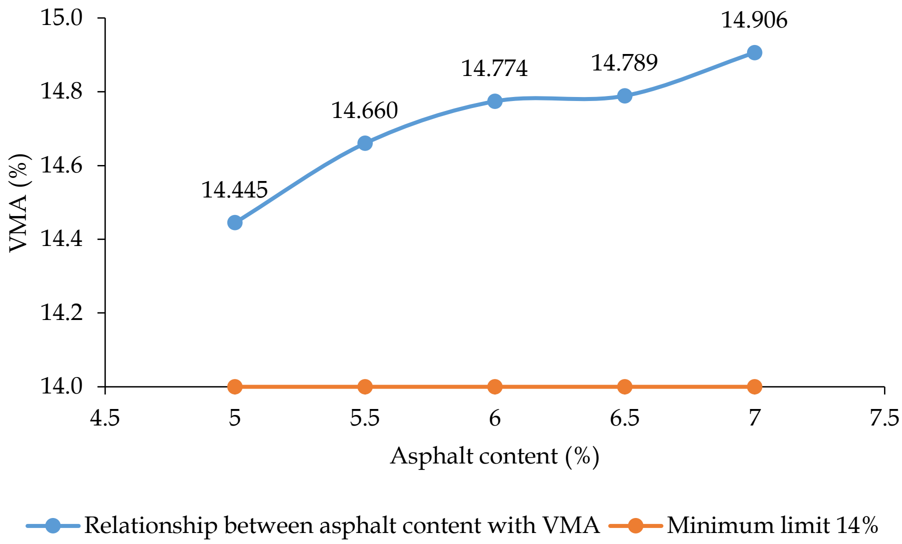

Figure 8. Graph of the relationship between asphalt content and (VMA)

Based on Figure 8, all Void in Mineral Aggregate (VMA) values meet the standards of the 2018 General Highways Specifications Revision 2 (2020), which is above 14%. It can be seen that the higher the asphalt content, the higher the VMA value. This indicates that the higher the asphalt content, the more asphalt fills the cavities between the aggregates in the pavement layer. In addition, the higher the asphalt content used, the lower the maximum mixture specific gravity (Gmm), thereby increasing the Void in Mineral Aggregate (VMA) value (Hýzl et al., 2016).

Void in Mix (VIM)

Void in Mix (VIM) is the air cavity between aggregate particles enclosed by asphalt in a compacted mixture and is expressed as a percentage. The Void in Mix (VIM) value is influenced by asphalt content, aggregate gradation, and density. The results of the Void in Mix (VIM) volumetric value calculation can be seen in Table 12.

Table 12. Void in Mix (VIM) Calculation Results

Asphalt content (%)	VIM (%)	Specification (%)
5.0	5.272	
5.5	4.327	
6.0	3.275	3–5
6.5	2.111	
7.0	1.068	

From Table 12, a graph of the relationship between asphalt content and Void in Mix (VIM) is obtained in Figure 9. Based on Figure 9, the Void In Mix (VIM) value that meets the standards of the 2018 General Bina Marga Specifications Revision 2 (2020) is 4.327% at 5.5% asphalt content and 3.275% at 6% asphalt content. Meanwhile, the asphalt content of 5%, 6.5% and 7% do not meet the specifications used. The graph shows that the higher the asphalt content used, the smaller the Void In Mix (VIM) value, this is because the higher the asphalt content, the more watertight and airtight the pavement layer is (John et al., 2021; Mohammed et al., 2023).

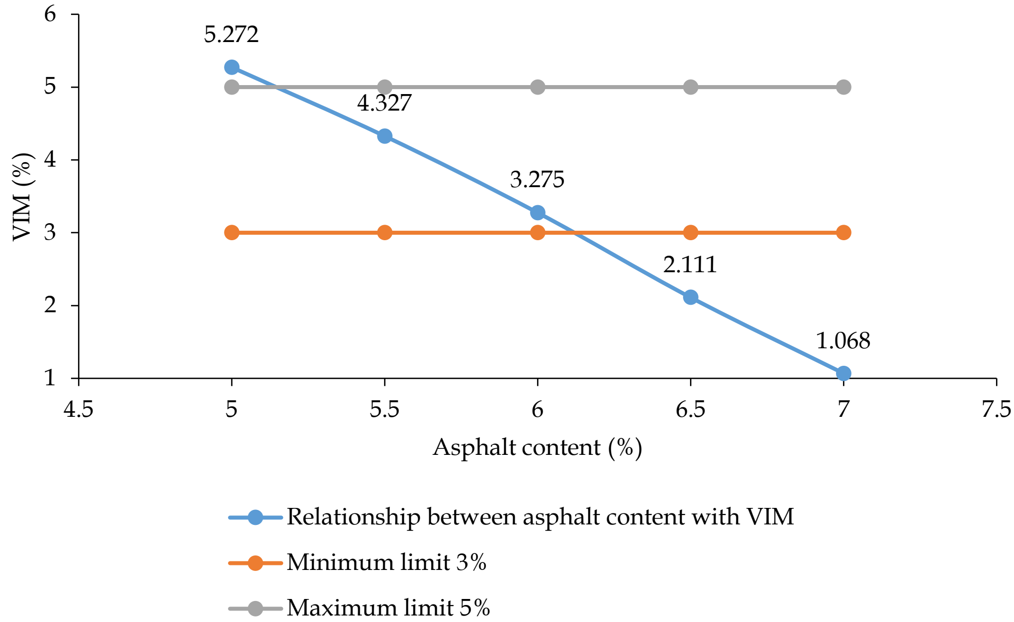

Figure 9. Graph of the relationship between asphalt content and Void in Mix (VIM)

Void Filled with Bitumen (VFB)

Void Filled with Bitumen (VFB) is the void between aggregates that is effectively filled with asphalt, expressed as a percentage. The Void Filled with Bitumen (VFB) value is influenced by aggregate gradation, asphalt content, immersion temperature, and compaction energy. The results of the volumetric Void Filled with Bitumen (VFB) calculation can be seen in Table 13.

Table 13. Calculation results for Void Filled with Bitumen (VFB)

Asphalt content (%)	VFB (%)	Spesification (%)
5.0	63.631	
5.5	70.801	
6.0	78.262	≥ 65
6.5	85.984	
7.0	92.868	

From Table 13, a graph of the relationship between asphalt content and Void Filled with Bitumen (VFB) is obtained in Figure 10.

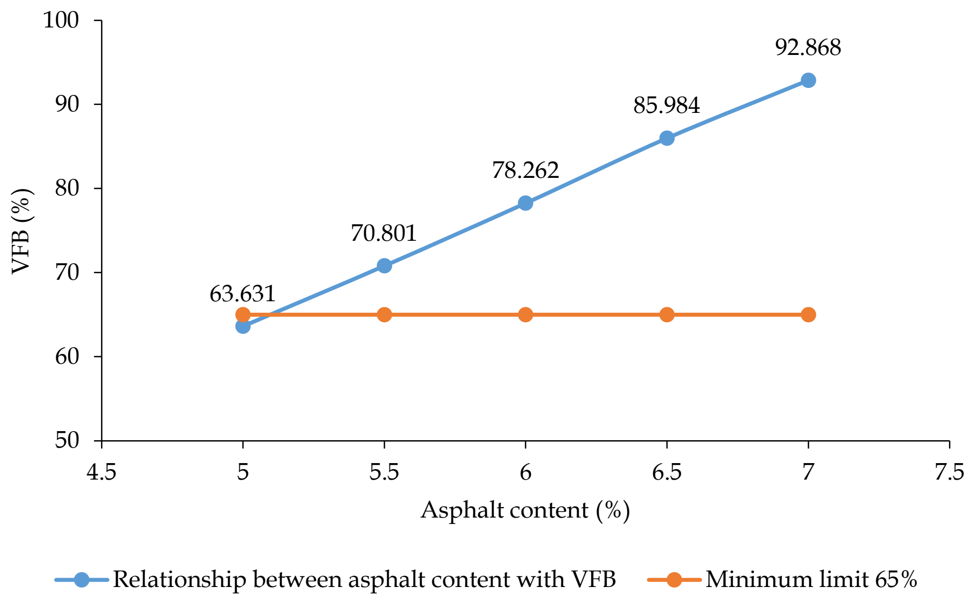

Figure 10. Graph of the relationship between asphalt content and VFB

Based on Figure 10, the Void Filled with Bitumen (VFB) value that meets the standards of the 2018 General Bina Marga Specifications Revision 2 (2020) is 70.801% for a 5.5% asphalt content, 78.262% for a 6% asphalt content, 85.984% for a 6.5% asphalt content, and 92.868% for a 7% asphalt content. However, the 5% asphalt content does not meet the specifications used. It can be seen that the higher the asphalt content used, the higher the Void Filled with Bitumen (VFB) value. This is because the higher the asphalt content, the more air cavities are filled by the asphalt. So the mixture's water and air tightness will be higher (Yohannes et al., 2020).

After obtaining the mechanical and volumetric values, the next stage is to carry out a recapitulation to facilitate analysis for determining the optimum asphalt content (KAO) as in Table 14.

Based on previous research conducted by a recapitulation of mechanical and volumetric values was obtained, namely Stability, Flow, MQ, VMA, VIM, and VFB, as shown in Table 14.

Table 14. Recapitulation of the results of mechanical and volumetric calculations

Parameter	Specifications	Asphalt content (%)				
		5.0	5.5	6.0	6.5	7
Stability (kg)	≥800 kg	2305.12	2060.11	1672.59	1519.66	1368.21
Flow (mm)	2-4 mm	1.990	1.997	3.747	3.910	3.993
SQM (kg/mm)	≥250 kg/mm	1338.54	1152.68	459.83	394.81	341.30
VMA (%)	≥ 14%	14.45	14.66	14.77	14.79	14.91
VIM (%)	3 - 5 %	5.272	4.327	3.275	2.111	1.068
VFB (%)	≥ 65 %	63.63	70.80	78.26	85.98	92.87

Based on the results of Table 14, for an asphalt content of 6%, all performance parameters meet the General Specification of Bina Marga 2018 Revision 2 (2020), so it is used as the Optimum Asphalt Content (OAC).

Indirect Tensile Fatigue Test (ITFT) Test Results

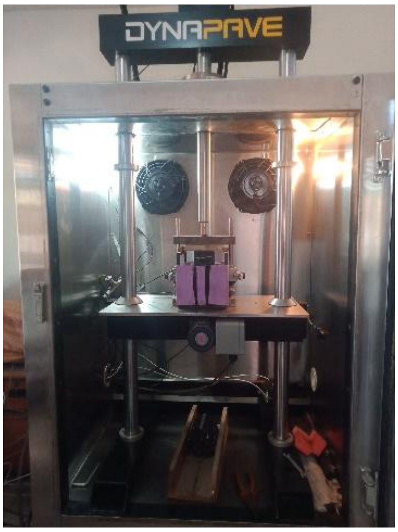

Figure 11. Indirect Tensile Fatigue Test (ITFT)

The results of the Indirect Tensile Fatigue Test (ITFT) test score can be seen in Table 15. From Table 15, a graph of the relationship between asphalt levels and Indirect Tensile Fatigue Test (ITFT) is obtained in Figure 12.

The increase in failure cycles in the test specimens indicates that the gradual addition of Modified Asphalt (MO) contributes to increased fatigue resistance. This phenomenon not only indicates a numerical increase in the number of cycles before failure but also reflects changes in the microstructural characteristics of the mixture.

Table 15. The results of the Indirect Tensile Fatigue Test (ITFT) score

Up to Asphalt (%)	Cycles
40% MO:60% MI	1861
50%MO:50%MI	2481
60%MO:40%MI	3401

The Modified Asphalt used in this study consisted of a mixture of asphalt, HDPE, and used oil. HDPE (High-Density Polyethylene) acts as a reinforcing agent, increasing the stiffness and cohesion of the mixture. HDPE forms a network structure that helps resist plastic deformation when the specimen is subjected to repeated loading. Studies by show that HDPE can increase the resilient modulus and extend the fatigue life of asphalt mixtures (Elnaml et al., 2023).

Meanwhile, used oil acts as a rejuvenator, restoring the binder's flexibility. The light fraction content in used oil reduces the viscosity of hard asphalt (asbuton), allowing the mixture to be more flexible and less prone to cracking when subjected to cyclic loading strain (El-labbad et al., 2022), stated that asphalt rejuvenated with used oil showed reduced excessive stiffness and increased resistance to premature cracking.

With this combination, the MO mixture provides a balance between flexibility and stiffness, two key characteristics for fatigue resistance. This aligns with the findings of Agha et al. (2023), who showed that asphalt modification with HDPE and a rejuvenator can increase fatigue life up to twofold compared to conventional mixtures.

From a practical perspective, this increased fatigue resistance has direct implications for longer road life, especially on heavy traffic routes. High proportions of MO mixtures can reduce the frequency of premature cracking, minimize maintenance requirements, and lower pavement lifecycle costs.

However, it should be noted that increasing the content of HDPE plastic and used oil is not always beneficial, such as research conducted by Suksiripattanapong et al. (2022), the optimum HDPE plastic waste content is 5% which provides maximum ITFT, but at 7% HDPE plastic content it causes the sample surface to crack. Several studies by Majidifard et al. (2019) and Mehmood et al. (2024) report that the use of used oil as an additive in asphalt recorded a decrease in the stiffness modulus when using 5-20% used oil, especially rutting deformation and fatigue cracking. Therefore, an evaluation of the optimum MO content limit is necessary, considering the balance between fatigue performance, structural stability, and economic aspects.

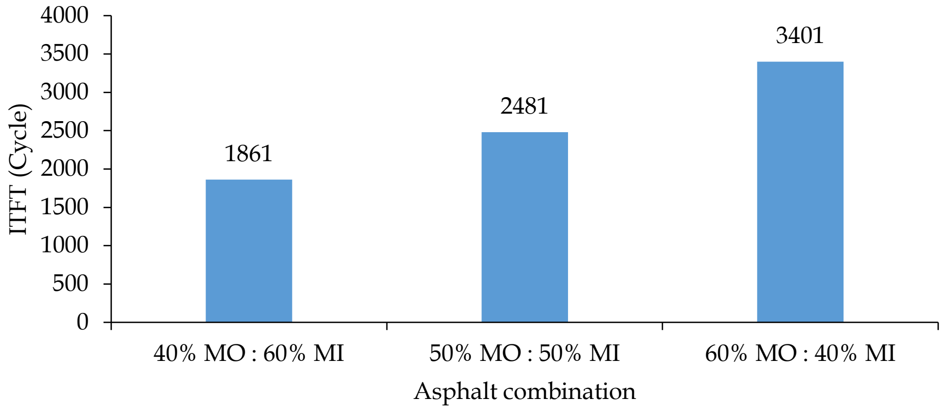

Figure 12. Graph of the relationship of asphalt rate with ITFT value

Conclusion

This study shows that the use of modified asphalt made from asbuton, used oil, and HDPE in the AC-BC mixture can significantly increase fatigue resistance. The trend of increasing fatigue performance along with the increasing proportion of asphalt modification indicates that the material has the potential as a more resilient pavement solution to repeated loads. Optimal performance was obtained at an optimum asphalt content of 6% (OAC) with a modified asphalt composition of 60%, which showed the best fatigue response based on ITFT testing. These findings support the utilization of waste such as used oil and HDPE plastic as sustainable additives in road construction, while increasing the utility value of asbuton as a local resource. The implication is that the use of this alternative material not only improves technical pavement performance but also contributes to more environmentally friendly and sustainable road construction practices. In the future, further studies are needed to produce the long-term performance of this mixture under real traffic and climate conditions, as well as testing of application methods in the field to validate the feasibility of large-scale implementation.

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Authors Contributions

Conceptualization, M.A.H., I.D.M.A.K., and I.A.O.S.S.; methodology, writing original draft preparation, M.A.H. and I.D.M.A.K.; validation, I.D.M.A.K; resources, M.A.H. All authors have read and agreed to published version of the manuscript.

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Conflict Interests

The authors declare no conflict of interest.

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