ANALYSIS OF THE EFFECT OF THERMOPLASTICS AND ELASTOMERS ON THE STIFFNESS AND RESISTANCE OF ASPHALT AT HIGH TEMPERATURES

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ABSTRACT

Indonesia, as a tropical country, faces serious challenges in maintaining the quality of road pavement due to extreme temperatures that can reach 57°C, as observed on the runway of Aji Pangeran Tumenggung Pranoto Airport in Samarinda. This study aims to analyze the effect of adding thermoplastic Low Density Polyethylene (LDPE) polymer and natural latex elastomer on the stiffness and resistance of 60/70 penetration asphalt at high temperatures. An experimental research methodology with a factorial design was used to evaluate 55 samples with varying polymer concentrations of 0%, 1%, 2%, 3%, 4%, and 5% through penetration (SNI 2456:2011), ductility (SNI 2432:2011), and softening point (SNI 2434:2011). The results showed that the addition of polymer significantly reduced the penetration and ductility values but increased the softening point and penetration index. LDPE thermoplastics showed superior effectiveness in increasing stiffness with an increase in softening point to 69.3°C compared to the base asphalt of 51°C. Based on the evaluation of standard KP 14 of 2021, the optimum concentration is 1-3% for thermoplastics and 1-4% for elastomers, providing the best balance between thermal resistance and flexibility required for sustainable road infrastructure.

Keywords: *Asphalt, Elastomer, Stiffness, Temperature, Thermoplastic*

1. INTRODUCTION

Indonesia is a tropical country that experiences two main seasons, namely the rainy season and the dry season. Indonesia's geographical characteristics, located on the equator, result in higher solar radiation intensity compared to countries with temperate climates. This condition is reinforced by Nur Laela Latifah's statement that tropical regions have high temperatures with an average minimum of 20°C (1). The characteristics of tropical regions include consistent high rainfall, humidity, and temperatures, minimal wind movement, strong sunlight intensity, and low heat exchange, which results in high atmospheric humidity. The phenomenon of global warming has further exacerbated the increase in temperature, creating an increasingly hot and challenging environment.

As a developing country, Indonesia continues to encourage growth in various development sectors, including the transportation sector, which is the backbone of community mobility and economic growth. Road infrastructure development becoming a strategic priority to support interregional connectivity. However, extreme temperatures during the dry season pose serious challenges to the quality and durability of asphalt pavement. Significant temperature increases can affect the structural integrity of road infrastructure, particularly asphalt pavement, which is a major component of Indonesia's pavement system.

The impact of high temperatures on the quality of asphalt pavement has been empirically proven through research showing a decrease in the pavement's load-bearing capacity. George et al. proved through their research that there was a degradation in stability values in asphalt samples that were immersed in higher temperatures (2). The study used asphalt material with specifications of 67.9 dmm penetration, 48°C softening point, 270°C flash point, and 290°C burning point. The results showed a negative correlation between temperature variation and *the Marshall quotient (*MQ) parameter, indicating a decline in asphalt quality as temperature increases.

This condition was confirmed through field observations conducted at Aji Pangeran Tumenggung Pranoto Airport, Samarinda, East Kalimantan. Although *overlay* had been carried out along *runways* 22 and 04 in October, damage in the form of *rutting* on the aircraft wheel tracks had been identified before the pavement reached its planned age. Measurements of *the runway* surface temperature showed temperatures reaching 57°C, which far exceeds the softening point of conventional asphalt. This condition highlights the urgency of developing pavement technology that can withstand extreme temperatures.

One technological innovation developed to address this problem is the modification of asphalt using polymer materials. Polymers are defined as materials formed from molecular units bound together through a chemical reaction called polymerization. Ebewele states that polymers are large molecules (macromolecules) formed through the repetition of small chemical units (3). Certain polymer characteristics show superior heat resistance compared to conventional asphalt, as well as relatively high elasticity.

Thermoplastics are a category of polymers that have a higher melting point than the softening point of asphalt, with *visco-elastic* properties that melt at high temperatures or under pressure, but solidify again when the temperature decreases or the pressure is released. Meanwhile, elastomers are a type of polymer with high elasticity that can reach 700% to 900%, with the characteristic of not melting at high temperatures but only softening.

Based on the problems identified, this study formulates three main research questions. First, how does the addition of polymers affect the stiffness and resistance of asphalt samples when exposed to high temperatures? Second, how does the effect of varying polymer types compare in terms of the stiffness and resistance of asphalt when exposed to high temperatures? Third, what is the optimal polymer mixture formula that meets the applicable specification standards?

To answer these questions, this study aims to analyze the effect of polymer addition on changes in asphalt stiffness and durability at high temperatures, compare the magnitude of the effect of each type of polymer mixture on asphalt characteristics, and determine the optimal type and content of polymer mixture in accordance with specification standards. This study is expected to make a significant contribution to the development of pavement technology that is resistant to extreme temperatures extreme temperatures, particularly to support transportation infrastructure in tropical Indonesia.

The benefits of this research include the development of scientific knowledge in the field of asphalt characteristic analysis and evaluation, the provision of references for academic activities in the Civil Engineering and Foundation Study Program, and a basis for consideration for further research in the field of asphalt modification. Thus, this research is expected to provide innovative solutions to improve the quality and durability of road infrastructure in Indonesia.

2. METHOD

This study uses an *experimental research* approach with a factorial design to evaluate the effect of polymer modification on the physical characteristics of 60/70 penetration asphalt. The experimental methodology was chosen to identify the causal relationship between variations in polymer type and concentration and changes in the mechanical properties of asphalt under extreme temperature conditions through a series of controlled laboratory tests.

The independent variables included two categories of modified polymers: *Low Density Polyethylene* (LDPE) thermoplastics and natural latex elastomers in the form of *crepe rubber*, with concentration gradations of 0%, 1%, 2%, 3%, 4%, and 5% relative to asphalt mass. The dependent variables consisted of stiffness and thermal resistance parameters measured through penetration values, ductility, softening point, and penetration index. Quality control was performed using standard unmodified asphalt samples as a comparison to evaluate the effectiveness of polymer addition.

Primary data was obtained through direct observation of *runway* pavement surface temperature measurements at Aji Pangeran Tumenggung Pranoto Airport in Samarinda for seven consecutive days to identify field thermal conditions. Test samples were prepared using a total of 55 specimens distributed across three types of tests: penetration (SNI 2432:2011), ductility (SNI 2432:2011), and softening point (SNI 2434:2011). Each polymer concentration variant was replicated as needed for testing to ensure the validity and reliability of the experimental results.

Data evaluation used penetration index calculations based on the Pfeiffer and Van Doormall formula, with function A calculated using the equation $A = (\log penT_1 - \log 800)/(T_1 - SP)$, followed by $PI = 20(1 - 25A)/(1 + 50A)$ calculations according to Indriyanti's methodology (4). A comparative analysis was conducted to identify the optimal polymer type and concentration based on the correlation graph between the variation in modification ( ) and the results of the penetration index ( ) ( ), then compared with the KP 14 Year 2021 specification standard.

Field observations were conducted at Aji Pangeran Tumenggung Pranoto Airport in Samarinda from November 12 to 18, 2024, while laboratory testing of asphalt samples was conducted at the Surabaya Aviation Polytechnic Asphalt Laboratory from January to April 2025.

3. RESULTS AND DISCUSSION

General Description of the Experimental Study

The experimental investigation of the impact of polymer additives on the mechanical characteristics and thermal stability of asphalt was designed to produce a modified asphalt formulation capable of maintaining structural integrity under extreme temperature conditions. This research refers to the regulation of the Decree of the Minister of Public Works and Public Housing Number 14 of 2021, with the main focus on achieving specifications for resistance to melting and permanent deformation under high traffic loads and exposure to extreme temperatures. According to Tjitjik & Suroso, asphalt is a *viscoelastic* material whose properties change due to temperature changes. At low temperatures, it is semi-solid, while at high temperatures, it is liquid (5). The modifiers used include *Low Density Polyethylene (*LDPE) *thermoplastic* polymers and *elastomer* polymers in the form of natural latex in the form of *crepe rubber.*

As stated by F. Eddy Poerwodiharjo & Fajar Setiabudi, modified asphalt is hard asphalt whose characteristics are modified by adding additives or *modifiers* to the asphalt in order to improve quality and produce high asphalt durability (6). Both types of polymers are selected based on their ability to increase asphalt stiffness while maintaining the necessary flexibility characteristics. This innovation is highly significant for the development of transportation infrastructure in tropical climates, where high temperatures and heavy traffic loads are common. pose a major challenge in maintaining pavement durability.

Material Characterization Research

Specifications of 60/70 Penetration Base Asphalt

The 60/70 penetration hard asphalt used as the base material underwent comprehensive characterization prior to the modification process. This material was selected because it has an optimal balance between stiffness and flexibility, making it suitable for *hot mix asphalt* applications. Initial characteristics were evaluated using three fundamental parameters: penetration value, ductility, and *softening point*, following the standard procedures of SNI 2434:2011, SNI 2456:2011, and SNI 2432:2011.

The test results showed a penetration value of 68.8 (0.1 mm), which is within the standard specification range for 60/70 penetration asphalt, indicating an appropriate level of consistency. The ductility parameter reached 120.7 cm at a temperature of 25°C, demonstrating adequate plastic deformation capacity before structural failure. Meanwhile, the softening point obtained was 51°C, indicating the critical temperature limit at which the asphalt begins to undergo a phase transition from semi-solid to a softer condition.

Thermoplastic LDPE Polymer Specifications

The modifier material, a *thermoplastic Low Density Polyethylene* (LDPE) polymer, has been characterized in detail to ensure compliance with specifications as shown in Table 1. Based on testing in accordance with ASTM standards, LDPE exhibits a density of 0.927 g/cm³ with a Vicat softening temperature of 95°C and *a melting point of* 121°C. Tensile strength at *yield* reaches 18 MPa with 100% elongation at break. According to Mashaan et al., polymers are generally organic compounds composed of hydrocarbon molecules (7). These characteristics indicate that LDPE has good thermal stability and adequate deformation capabilities for asphalt modification applications.

Table 1. Specifications of Low Density Polyethylene (LDPE)

Physical Properties	Test Method (ASTM)	Value
Density	D1505	0.927 g/cm³
Vicat Softening Temperature	D1525	95 °C
Melting Point	D3418	121 °C
Tensile Strength at Yield	D746	18 MPa
Elongation at Break	D638	100

Specifications of Natural Latex *Elastomer* Polymer

The *elastomer* polymer used is natural latex in the form of *crepe rubber*, characterized according to SNI ISO standards as presented in Table 2. This material exhibits initial plasticity of 45.5 and plasticity after heating of 37.0. The impurity content is very low at 0.016% with ash content 0.37%. The Mooney viscosity 50 ML (1+4) at 100°C reaches 74.4, indicating rheological properties suitable for asphalt modification applications. According to Rahmawati, the high elasticity of *elastomers* is due to the very few cross-links in *the elastomer* polymer *(*8). This characteristic indicates the high quality of the natural *elastomer* used in the study.

Table 2. Specifications of Natural Latex in Crepe Rubber Form

Physical Properties	Test Method (ASTM)	Value
Initial Plasticity	SNI ISO 2930:2013	45.5
Plasticity After Heating	SNI ISO 2930:2013	37.0
Impurity Content	SNI ISO 249:2015	0.02
Ash Content	SNI ISO 247:2012	0.37
Mooney Viscosity, 50 mL (1+4) at 100°C	SNI ISO 289-1:2017	74.4

Mixing and Sample Preparation Methodology

The *hot-cold mixing method* was applied to optimize polymer integration into the asphalt matrix. This technique combines asphalt at high thermal conditions with polymer at room temperature, referring to the methodology developed by Ling et al. in their study on the effect of *Crumb Rubber Modifier* (CRM) on asphalt properties (9). The mixing process was carried out using a *high-speed laboratory mixer* equipped with a controlled heating system at a temperature of 160 ± 5°C for a duration of 60 minutes. This methodology was chosen to optimize thermal energy efficiency and prevent thermal degradation of polymer materials that are sensitive to excessive heat.

The mixing procedure began with heating the 60/70 penetration asphalt to reach an operating temperature of 160°C. Next, the polymer was added gradually according to the predetermined ratio (1%, 2%, 3%, 4%, and 5% of the asphalt weight) and mixed for ±30 minutes using a high-speed mixer while maintaining thermal conditions. After the mixing process is complete, homogeneity is evaluated through *a smear test* by taking a sample of hot asphalt and spreading it thinly on cardboard. Visual observation is carried out to ensure that there is no agglomeration or polymer particles that are not completely dispersed in the asphalt matrix.

Evaluation Results of Modified Asphalt

Characteristics Penetration Test Analysis Results

The consistency and stiffness of the modified asphalt samples were evaluated through penetration tests in accordance with SNI 2456:2011 and ASTM D5/D5M at a controlled temperature of 25°C. The test results, as shown in Table 3, indicate a downward trend in penetration values with increasing polymer concentration in both types of modifiers used.

Table 3. Modified Asphalt Penetration Test Results

Sample Code	Mixture Composition	Penetration Value (dmm)
A0	Pen 60/70 Asphalt	68
P1	Pen 60/70 asphalt+ 1% Thermoplastic	66.9
P2	Pen 60/70 asphalt+ 2% thermoplastic	64.3
P3	Pen 60/70 asphalt+ 3% thermoplastic	62.5
P4	Asphalt Pen 60/70+ 4% Thermoplastic	59.6
P5	Asphalt Pen 60/70+ 5% Thermoplastic	58.4
E1	+ e 60/70 Asphalt 1% Elastomer	66.2
E2	Pen 60/70 asphalt+ 2% elastomer	65.7

Sample Code	Mixture Composition	Penetration Value (dmm)
E3	Pen 60/70 asphalt+ 3% elastomer	61.8
E4	Pen 60/70 asphalt+ 4% elastomer	60
E5	Pen 60/70 asphalt+ 5% elastomer	59.3

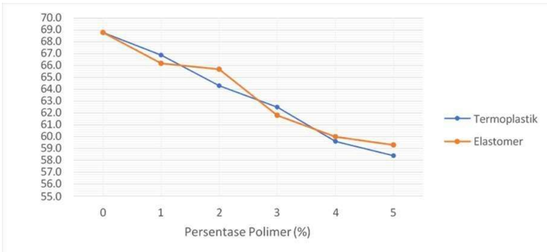

Figure 1. Graph of the Relationship between Polymer Content and Penetration Value

Based on the data in Table 3 and the visualization in Figure 1, the addition of both types of polymers effectively reduces the penetration value, indicating increased asphalt stiffness. However, samples with concentrations ≥4% showed penetration values below 60 dmm, which did not meet the specifications of KP 14 of 2021. *Thermoplastic* polymers showed higher effectiveness in increasing stiffness compared to *elastomers*, as indicated by the steeper gradient of penetration value decrease in Figure 1.

Evaluation of Modified Asphalt Ductility

Ductility testing was conducted to measure the elasticity of modified asphalt in accordance with SNI 2432:2011 and ASTM D113 at a temperature of 25°C. The test results, as shown in Table 4, indicate a trend of decreasing ductility values with increasing polymer concentration.

Table 4. Results of Modified Asphalt Ductility Testing

Sample Code	Mixture Composition	Ductility Value (cm)
A0	Pen 60/70 Asphalt	120.7
P1	Pen 60/70 asphalt+ 1% Thermoplastic	118.3
P2	Asphalt Pen 60/70+ 2% Thermoplastic	115.3
P3	Asphalt Pen 60/70+ 3% Thermoplastic	112.7
P4	Asphalt Pen 60/70+ 4% Thermoplastic	105.45
P5	+ e 5% Thermoplastic	99.6
E1	Asphalt Pen 60/70+ 1% Elastomer	120.7
E2	Pen 60/70 asphalt+ 2% elastomer	117.2
E3	Pen 60/70 asphalt+ 3% elastomer	116.4
E4	Asphalt Pen 60/70+ 4% Elastomer	114.3
E5	Pen 60/70 asphalt+ 5% elastomer	108.7

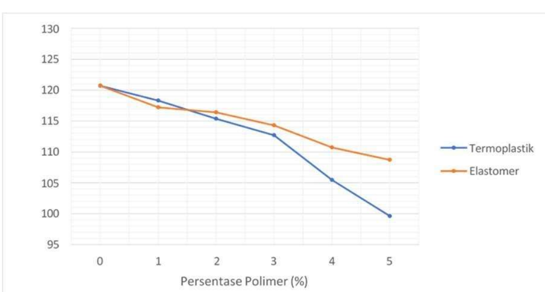

Figure 2. Graph of the Relationship between Ductility Values and Polymer Percentage

Based on the data analysis in Table 4 and the visual representation in Figure 2, modification with polymer reduces the elasticity of asphalt. Excessive reduction in ductility can cause pavement to be susceptible to fatigue cracking due to repeated traffic loads. Sample P5 with a ductility value of 99.6 cm does not meet the minimum standard of 100 cm according to KP 14 of 2021.

Softening Point Analysis

The softening point was evaluated to determine the critical temperature at which asphalt begins to soften before transitioning to the liquid phase, referring to SNI 2434:2011 and ASTM D36. The test results are presented comprehensively in Table 5.

Table 5. Modified Asphalt Softening Point Test Results

Sample Code	Mixture Composition	Softening Point Value (°C)
A0	Pen 60/70 Asphalt	51
P1	Pen 60/70 asphalt+ 1% Thermoplastic	54.1
P2	Pen 60/70 asphalt+ 2% thermoplastic	59
P3	Pen 60/70 asphalt+ 3% thermoplastic)	64.4
P4	Asphalt Pen 60/70+ 4% Thermoplastic	66.8
P5	Asphalt Pen 60/70+ 5% Thermoplastic	69.3
E1	Asphalt Pen 60/70+ 1% Elastomer	52
E2	+ e 60/70 Asphalt 2% Elastomer	52.7
E3	Asphalt Pen 60/70+ 3% Elastomer	54.9
E4	Pen 60/70 asphalt+ 4 % elastomer	55.6
E5	Pen 60/70 asphalt+ 5% elastomer	56.2

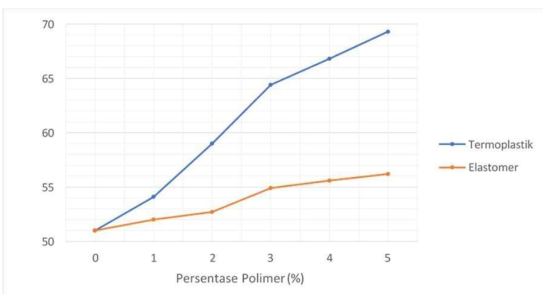

Figure 3. Graph of the Relationship between Polymer Percentage and Softening Point Value

The results of the analysis in Table 5 and the visualization in Figure 3 show a significant increase in the with the addition of polymer, indicating increased resistance to high temperatures and reduced thermal sensitivity. *Thermoplastic* polymers show superior effectiveness in increasing the softening point compared to *elastomers*, as indicated by the steeper gradient in Figure 3.

Penetration Index Calculation

The sensitivity of asphalt to temperature changes was evaluated through the calculation of the Penetration Index using the Pfeiffer and Van Doormall equations. The calculation results presented in Table 6 show an increase in the penetration index value with the addition of polymer concentration.

Table 6. Penetration Index Values of Modified Asphalt

Sample Code	Mixture Composition	Penetration Index
A0	Pen 60/70 asphalt	-0.161
P1	Asphalt Pen 60/70+ 1% Thermoplastic	0.52
P2	Pen 60/70 asphalt+ 2% thermoplastic	1.494
P3	Pen 60/70 asphalt+ 3% thermoplastic	2,474
P4	Asphalt Pen 60/70+ 4% Thermoplastic	2,771
P5	Asphalt Pen 60/70+ 5% Thermoplastic	3,092
E1	Asphalt Pen 60/70+ 1% Elastomer	-0.014
E2	Pen 60/70 asphalt+ 2% elastomer	0.137
E3	Pen 60/70 asphalt+ 3% elastomer	0.491
E4	Pen 60/70 asphalt+ 4% elastomer	0.57
E5	Pen 60/70 asphalt+ 5% elastomer	0.681

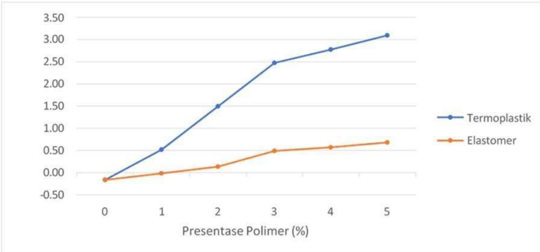

Figure 4. Graph of the Relationship between the Penetration Index and Polymer Percentage

Synthesis and Discussion of Results

A comprehensive analysis of all test parameters shows that modifying asphalt with *thermoplastic* polymers and *elastomers* produces different characteristics in terms of stiffness and thermal sensitivity. As the polymer concentration increases, there is an increase in the penetration index value, indicating a decrease in sensitivity to temperature changes, but accompanied by a decrease in ductility, which indicates a reduction in the elasticity of the material. This phenomenon demonstrates a *trade-off* between resistance to permanent deformation and resistance to fatigue cracking. Asphalt with low temperature sensitivity has superior resistance to *rutting* but is more susceptible to *cracking.* To optimize the performance of modified asphalt, a balance between these two characteristics is required through precise specification control.

Based on an evaluation of the KP 14 Year 2021 standard, samples with *thermoplastic* concentrations of 4% and 5% and *elastomer concentrations* of 5% did not meet specifications because they had penetration and ductility values below the minimum requirements. This indicates that these samples experienced excessive stiffness, which can cause brittleness and susceptibility to cracking (10). The results of this study are in line with the findings of Al-Abdul Wahhab et al., which show that an optimum mixture of 3% HDPE plastic waste produces a penetration parameter of 64.33 mm, a softening point of 54°C, and ductility of 115.1 cm (11). Similarly, research by Ameri et al. confirms that the better modified asphalt sequences to use in succession are SIR20 rubber modified asphalt, *gilsonite* modified asphalt, and PET modified asphalt in terms of thermal sensitivity (12). Meanwhile, Yu et al. in their study on asphalt sensitivity to temperature showed that the penetration index value increases with increasing rubber content, which is consistent with the findings of this study (13). Lastra-González et al. also reported that the stability, *flow,* VFA, and MQ values tend to increase with increasing polymer additive content (14).

This finding contributes significantly to the development of optimal modified asphalt formulations for Indonesia's tropical climate, where resistance to high temperatures is a top priority without sacrificing the flexibility needed for resistance to repeated traffic loads (15).

4. CONCLUSION

Conclusion

This study proves that modifying 60/70 penetration asphalt with thermoplastic LDPE polymer and natural latex elastomer in the form of crepe rubber has a significant impact on the mechanical characteristics and thermal stability of asphalt. The addition of both types of polymers consistently reduces penetration and ductility values, but increases the softening point and penetration index, indicating increased stiffness and resistance to deformation at high temperatures. Thermoplastic LDPE polymer shows superior effectiveness in increasing stiffness compared to elastomer, with an increase in softening point of up to 69.3°C at a concentration of 5% compared to 51°C for base asphalt. However, there is a trade-off relationship between deformation resistance and material flexibility, where increased stiffness is accompanied by a decrease in elasticity, which can increase susceptibility to fatigue cracking. Based on an evaluation of the standards of the Decree of the Minister of Public Works and Public Housing Number
14 of 2021, the optimum concentration is an asphalt sample with a 3% mixture of thermoplastic polymer additives, which shows the best balance between increased thermal resistance and the maintenance of the required flexibility. This formulation has the potential to improve the durability of road pavements in Indonesia's tropical climate, which faces challenges of high temperatures and heavy traffic loads, thereby contributing to the development of more sustainable and economical transportation infrastructure.

Recommendations

Further research is needed to optimize the formulation of modified asphalt through a combination of both types of polymers in the right ratio to achieve synergy between stiffness and flexibility. Long-term evaluation of the performance of hot mix asphalt using modified asphalt in real field conditions is necessary to validate laboratory results, including testing for rutting resistance, fatigue cracking, and aging characteristics. The development of more efficient and economical mixing methods needs to be explored to support industrial-scale implementation, as well as the investigation of alternative polymers that are more environmentally friendly and cost-effective. Comparative studies with other modifiers such as Styrene Butadiene Styrene (SBS), Crumb Rubber Modifier (CRM), and gilsonite will provide a comprehensive perspective on the selection of optimal modifier materials for specific conditions in Indonesia, thereby producing technical guidelines that can be adopted in national road construction standards.

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