



# Effect of resin and catalyst addition on the characteristics of asphalt concrete wearing course (AC-WC) for coastal area

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## Abstract

The Pantura Road connecting Semarang and Demak frequently experiences tidal flooding (rob) due to severe land subsidence and rising sea levels. Excessive groundwater extraction in industrial areas and global warming accelerate pavement deterioration, causing cracks, potholes, and deformation that threaten road safety. To address this issue, this study aims to improve the durability of Asphalt Concrete Wearing Course (AC-WC) through the addition of catalyst resin as a chemical modifier. A total of 81 samples were prepared with resin contents of 0%, 2%, and 4%, resulting in nine mixture combinations with three replicates each. The asphalt used was penetration grade 60/70, while aggregate and asphalt properties were tested according to the Bina Marga 2018 Technical Specifications (Revision 2). Laboratory tests included Marshall stability, flow, fatigue, Marshall Quotient, and volumetric parameters (VIM, VMA, and VFA). Specimens were submerged in tidal water for 7, 14, and 21 days to simulate continuous tidal inundation. The tidal water was analyzed for Total Suspended Solids (TSS), Total Dissolved Solids (TDS), chloride, sulfate, salinity, and pH. Statistical analysis was performed to evaluate the effects of resin content and immersion duration on AC-WC performance. The findings indicate that the Job Mix Formula (JMF) of modified AC-WC immersed for 7 days with 2% and 4% resin meets the Bina Marga 2018 specifications, while longer immersion durations reduced stability and durability. Catalyst resin modification shows potential to enhance pavement resistance to tidal flooding in coastal regions.

## Keywords

Rob, Modified Asphalt, Stability

## Introduction

The Pantura Road between Semarang and Demak faces increasing tidal flooding due to sea-level rise, land subsidence, and saltwater intrusion along the northern coast of Java. This causes frequent saltwater inundation that accelerates asphalt pavement

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deterioration, as saltwater weakens the asphalt–aggregate bond, leading to stripping and reduced pavement durability.

Researchers and practitioners have explored various material and technical approaches to improve pavement durability in coastal areas, including thermoplastic and thermoset asphalt modified with polymers (SBS, PU) and the use of epoxy, waterborne-epoxy, and other resins as modifiers to enhance stiffness, adhesion, and resistance to permanent deformation. Laboratory and review studies indicate that thermoset resins (e.g., epoxy, polyurethane) improve Marshall stability, rutting resistance, and binder–aggregate adhesion, while waterborne and emulsified epoxy allow low-temperature or cold applications. Experimental studies also simulate coastal conditions through wet–dry cycles and exposure to contaminated water [1]. Although many studies reports improved mechanical properties with resin or epoxy modification, recent research highlights that the corrosive effects of seawater (salt/chloride) at the asphalt aggregate interface can trigger damage mechanisms (sea-salt erosion, stripping) that remain insufficiently examined particularly under conditions of high NaCl concentration, prolonged wet dry cycles, and land subsidence prolonging inundation. Most epoxy-modified asphalt studies focus on thermal and fatigue performance, while investigations on salt erosion resistance, resin chloride ion interactions, and environmental effects are still limited. Field studies on tidal flood exposed Pantura roads are also scarce, leaving a gap between laboratory findings and real-world performance [2]. This study examines the effect of Gil Sonite Resin on AC-WC asphalt performance. Based on the 2018 Public Works standards, adding up to 8% resin increased stability (1274.6 kg), flow (2.70 mm), and Marshall Quotient (472.09 kg/mm), while VIM and VMA slightly decreased but remained within acceptable limits [3]. This study proposes developing a saline-resistant asphalt formulation using a combination of thermoset resins (epoxy/PU) and catalysts or compatibilizers. The approach includes: (1) designing resin–curing systems resistant to chloride interaction, (2) incorporating compatibilizers or nanoparticles to strengthen the binder aggregate interface and reduce stripping, and (3) testing under simulated tidal conditions with controlled NaCl concentration, wet–dry cycles, thermal exposure, and field trials on the Semarang Demak Pantura segment. Integrating insights on epoxy and waterborne-epoxy adhesion with a focus on resin–salt interactions, this concept aims to improve Marshall stability, rutting resistance, and stripping performance, while assessing environmental and economic feasibility [4].

This study aims to enhance asphalt pavement resistance to seawater exposure through resin–catalyst modification. Specifically, it examines the effect of varying resin content on the Marshall stability of asphalt mixtures under saline conditions simulating tidal flooding on the Semarang–Demak Pantura Road. Laboratory tests include preparing modified asphalt mixes, immersing them in tidal water, and evaluating Marshall characteristics. The results are expected to provide a scientific basis for using resin–catalyst modifiers to improve pavement quality in coastal areas.

## Method

### *Tools and materials*

This study employed various tools and materials to analyze the characteristics of resin–catalyst modified asphalt exposed to tidal water from the Semarang–Demak Pantura Road (Figure 1). Equipment included aggregate and asphalt testing instruments following the Marshall method. Aggregate tests utilized a Los Angeles abrasion machine, standard sieves for gradation analysis, a drying oven, specific gravity tools such as a pycnometer and balance, and a Sand Equivalent apparatus to assess fine aggregate cleanliness.

Asphalt testing utilized penetration, softening point, flash and fire point, ductility, and solubility apparatus to evaluate purity and stability against solvents. The Marshall test employed a 3000 kg loading machine with a proving ring and flow gauge. Cylindrical molds (10.2 cm diameter), manual compactor, extractor, and temperature-controlled water bath were used for specimen preparation in accordance with ASTM standards [5]. The materials used include Pen 60/70 asphalt, resin and catalyst, coarse and fine aggregates, filler, and tidal floodwater. Pen 60/70 asphalt was selected for its stability and flexibility under tropical conditions. The resin and catalyst, sourced from chemical suppliers, were used to enhance asphalt–aggregate adhesion and seawater resistance. Previous studies indicate that saltwater exposure can alter asphalt binder chemistry and accelerate adhesion failure [6]. Therefore, resin or epoxy modification is considered effective in strengthening the asphalt–aggregate bond and improving resistance to moisture and salt-induced erosion [7][8].



Figure 1. Resin

Resin is transparent, insoluble in water, and flammable. According to several sources, organic resin has been used since ancient times as a varnish or adhesive, such as the resin used in making sculptures. Technological developments have led to the discovery of chemical resins, which are used for purposes such as melamine, epoxy, acrylic, and coatings to provide a glossy effect, as well as for fragrance blends. A catalyst is a

substance used to accelerate a reaction, where the catalyst can provide active sites that bring reactants together and channel energy in the form of heat (Figure 2).



Figure 2. Catalyst

Catalysts are used because of their very important role and are needed in various industries. The demand for catalysts in the industrial world tends to increase, due to their economical use in speeding up reactions. Catalysts can accelerate reactions, but not all chemical reactions. For example, a catalyst can speed up the rate of a hydrogenation reaction, but it is not effective when used in hydrogenation reactions or in oxidation reactions. This is closely related to the physical and chemical properties of the catalyst, depending on the materials used.

Coarse and fine aggregates and filler were sourced from AMP PT. Perwita Karya Sembung, Batang, Central Java, complying with SNI 03-1968-1990 for hot-mix asphalt aggregates [9]. Tidal floodwater was collected directly from the Semarang–Demak Pantura Road to simulate real saline conditions affecting pavement performance [10][11], with laboratory freshwater used for comparison. This combination of materials and methods aims to representatively assess the performance of resin–catalyst modified asphalt under saline and corrosive environments (Figure 3 and 4).



Figure 3. Asphalt before soaking



Figure 4. Asphalt after soaking

### Research methods

All tests were conducted in accordance with relevant Indonesian National Standards (SNI) and ASTM standards. The research stages included material inspection, asphalt mix design, specimen preparation, immersion, and Marshall characteristic testing.

#### 1. Material inspection

The initial stage involved testing the properties of asphalt mix materials, including coarse and fine aggregates, filler, and Pen 60/70 asphalt, to ensure compliance with Public Works (2010), SNI, and ASTM standards. Aggregate tests covered specific gravity and absorption [12], abrasion [13], particle shape [14], adhesion [15], and Sand Equivalent [16] for cleanliness. Pen 60/70 asphalt was tested for penetration, softening point, flash and fire point, specific gravity, ductility, weight loss, and solubility following SNI and ASTM D2042-76 standards [17] to ensure thermal and chemical stability. Tidal floodwater used for immersion was collected from the inundation area on Sriwulan Street, Sayung, Demak Regency, and tested for pH, chloride, sulfate, and alkalinity parameters.

#### 2. Asphalt mix design and production

After all materials met specifications, the asphalt mix was designed using the Marshall method with varying asphalt contents around the optimum (Pb). Three specimens were prepared for each variation, totaling 81 samples covering different resin contents and immersion durations, with resin–catalyst combinations of 0%, 2%, and 4%. Mixing was conducted at 145°C–155°C according to asphalt kinematic viscosity [18], and compaction at 110°C–135°C using a Marshall hammer with 75 blows per side, following heavy-traffic standards (SNI 06-2489-1991). Specimens were then stored at room temperature for 24 hours before weighing and height measurement for volumetric analysis. All AC–WC mixtures with resin (0–6%) and steel fiber (0–6%) met the 2018 Bina Marga Rev. 2 specifications. Increasing resin and steel fiber contents consistently raised VIM values, from 3.68% (0% resin–0% fiber) to a maximum of 4.93% (4% resin–4% fiber). Marshall stability remained above the 800 kg requirement, ranging from 1505.27 kg to the highest value of 2159.74 kg at 2% resin and 4% steel

fiber [19]. The optimum asphalt content (OAC) for the tested porous asphalt mix was 5.00%. Marshall, Cantabro Loss, and Asphalt Flow Down tests confirmed that this binder content meets technical requirements. Proper aggregate gradation was found to be crucial for maintaining voids and permeability, while cellulose fiber improved abrasion resistance and mix stability. Overall, the mix shows strong potential for durable pavement applications under environmental and traffic loads [20].

### 3. Immersion of test objects

The immersion media consisted of natural tidal floodwater. Two immersion patterns were applied: continuous and intermittent, each with durations of 7, 14, and 21 days. In the intermittent pattern, samples were submerged for 12 hours and then air-dried for 12 hours before re-immersion, simulating real tidal flooding fluctuations in coastal areas [10].

### 4. Marshall test

After immersion, specimens were conditioned in a 60°C water bath for 30 minutes and then tested using the Marshall apparatus to determine stability (kg/kN) and flow (mm). The Marshall Quotient (MQ) was calculated as the ratio of stability to plastic flow (ASTM D1559, 2012). Additionally, density, VIM (Void in Mix), VMA (Void in Mineral Aggregate), and VFA (Void Filled with Asphalt) were obtained to evaluate mix quality according to SNI 06-2489-1991 and Public Works specifications (2010).

### 5. Data analysis

The final stage involved data analysis. Stability, flow, MQ, VIM, VMA, and VFA values were plotted against immersion duration and type of medium to observe changes in mix characteristics. Results from laboratory water immersion at 7, 14, and 21 days were compared to assess the effect of exposure time on mix durability. The analysis aimed to identify the relationship between salt ion content, Marshall stability reduction, and volumetric property changes.

## Results

The performance evaluation of the resin-catalyst modified AC-WC mixtures under continuous tidal (rob) water immersion shows that the mixture containing 50% slag aggregate and 6% LDPE is the only composition that satisfies the 2018 Bina Marga Technical Specification (Revision 2) at immersion ages of 7, 14, and 21 days. All other mixtures—those incorporating 0% or 100% slag combined with 0–18% LDPE—failed to meet the required criteria, particularly due to excessive deviations in air void values, rendering them unsuitable for road pavement applications [21]. This study was conducted through several stages, including material preparation, determination of asphalt content, specimen fabrication, and laboratory testing. Aggregates were obtained from PT. Perwita Karya Sembung, Batang, Central Java. All specimen

preparation, material testing, asphalt testing, and Marshall tests were carried out at the Road Transportation Laboratory, Sultan Agung Islamic University, Semarang. The use of supporting tools aimed to facilitate testing and ensure optimal results (Table 1,2, and 3). Subsequently, the specimens were prepared according to the predetermined compositions using modified asphalt with a binder content of 5.8%. The compositions used are presented below, while the additional materials were adjusted based on Table 4.

Table 1. Tidal water testing

No	Test Parameter	Unit	Test Result	
			Tidal Flood Water	Regular Water
1	Total Suspended Solids (TSS)	mg/L	39	29
2	Total Dissolved Solids (TDS)	mg/L	1237	939
3	Chloride (Cl)	mg/L	9551	754
4	Sulfate (SO <sub>4</sub> )	mg/L	2001	598
5	Salinity	g/L	22.59	16.95
6	pH	—	7.14	6.98

Source: Research Results of Juny Andri (2023)

Table 2. Asphalt pen 60/70 testing

Test Item	Test Result	Min	Max	Test Method	Unit
Penetration	65	50	80	SNI 06-2456:1991	0.1 mm
Softening Point	55.56	54	—	SNI 06-2434:1991	°C
Flash Point	357	232	—	SNI 06-2433:1991	°C
Ductility	151.5	50	—	SNI 06-2432:1991	cm
Weight Loss	59.80	54	—	SNI 06-2440:1991	%

Tabel 3. Research results on physical and mechanical properties of aggregates

No	Type of Test	Method	Requirement	Result	Remark
<b>A. Coarse Aggregate</b>					
1	Abrasion using Los Angeles Machine	SNI 03-2417-2008	Max. 40%	14.05%	Meets requirement
2	Adhesion of Aggregate to Asphalt Pen 60/70	SNI 03-2439-2011	Min. 95%	99%	Meets requirement
3	Flat and Elongated Particles	ASTM D4791-10	Max. 10%	8.79%	Meets requirement
4	Material Passing No. 200 Sieve	ASTM C117:2012	Max. 1%	0.7%	Meets requirement
5	Water Absorption by Aggregate	SNI 03-1969-1990	Max. 3%	1.593% (½ in) / 2.124% (¾ in)	Meets requirement
6	Bulk Specific Gravity	SNI 03-1969-1990	Min. 2.5	2.671% (½ in) / 2.682% (¾ in)	Meets requirement
<b>B. Fine Aggregate</b>					
1	Material Passing No. 200 Sieve	SNI 03-4142-1996	Max. 15%	11.56%	Meets requirement
2	Angularity	SNI 03-6877-2002	Min. 45%	47.92%	Meets requirement
3	Water Absorption by Aggregate	SNI 03-1969-1990	Max. 3%	1.593% (sand) / 2.124% (stone dust)	Meets requirement
4	Bulk Specific Gravity	SNI 03-1969-1990	Min. 2.5	2.751% (sand) / 2.752% (stone dust)	Meets requirement

Tabel 4. Manufacture of test objects

No	Resin (%)	Catalyst (%)	Samples	For 3 Tests
1	0	0	3	9
2	0	2	3	9
3	0	4	3	9
4	2	0	3	9
5	2	2	3	9
6	2	4	3	9
7	4	0	3	9
8	4	2	3	9
9	4	4	3	9
<b>Total</b>			<b>27</b>	<b>81</b>

To determine the optimum asphalt content, asphalt mixtures were prepared using asphalt contents ranging from 4% to 6%, with an increment of 0.5% for each test. In accordance with Bina Marga standards, six parameters were evaluated to determine the optimum content, namely stability, flow, Marshall Quotient (MQ), Voids Filled with Asphalt (VFA), Voids in Mix (VIM), and Voids in Mineral Aggregate (VMA) Table 5. Subsequently, once all specimens were prepared, the Marshall test was conducted, and the test results are presented in the appendix.

Table 5. Composition job mix design

No.	Material	Percentage (%)	Weight (gram)
1	Stone Dust	40.0	480.0
2	Sand	3.0	36.0
3	Medium Aggregate ( $\frac{1}{2}$ in)	25.0	300.0
4	Coarse Aggregate ( $\frac{3}{8}$ in)	25.0	300.0
5	Filler	1.2	14.4
6	Asphalt	5.8	69.6
<b>Total</b>		<b>100.0</b>	<b>1200.0</b>

## Discussion

The test results after seven days of immersion with several variations indicate that the Air Voids (VIM) values generally meet the specifications for road pavement applications. However, one specimen, namely variation 9, did not meet the requirement, as its VIM value was 5.11%, exceeding the specified limit of 3–5%. Meanwhile, the values of Voids in Mineral Aggregate (VMA), Voids Filled with Bitumen (VFB), Marshall Stability, Flow, and Marshall Quotient were all within the acceptable range according to the 2018 Bina Marga Technical Specifications (Revision 2). A comparison of the VIM, VMA, and VFB values shows that, although most variations met the criteria, one variation was deemed unsuitable for pavement use due to its VIM value exceeding 5%, thereby not complying with the 2018 Bina Marga Technical Specifications (Revision 2).

The test results after fourteen days of immersion with several variations indicate that none of the Air Voids (VIM) values met the specifications for road pavement (Figure 5), as all exceeded the allowable limit of 3–5%. However, the values of Voids in Mineral Aggregate (VMA) Figure 6, Voids Filled with Bitumen (VFB) Figure 7, Marshall Stability, Flow, and Marshall Quotient were all within the acceptable range according to the 2018

Bina Marga Technical Specifications (Revision 2). A comparison of the VIM, VMA, and VFB values shows that all specimens were unsuitable for pavement application because their VIM values exceeded 5%, thereby not complying with the 2018 Bina Marga Technical Specifications (Revision 2).

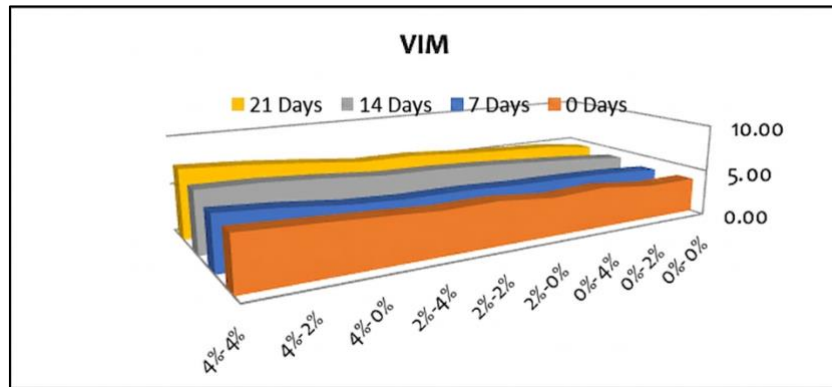


Figure 5. VIM recapitulation of catalyst resin mixture

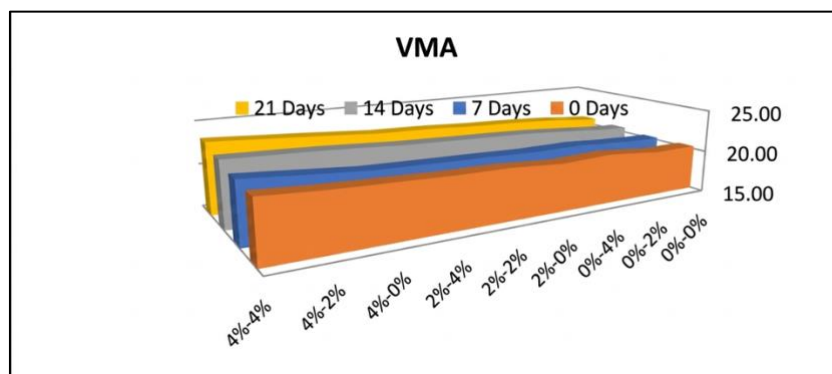


Figure 6. VMA recapitulation of catalyst resin mixture

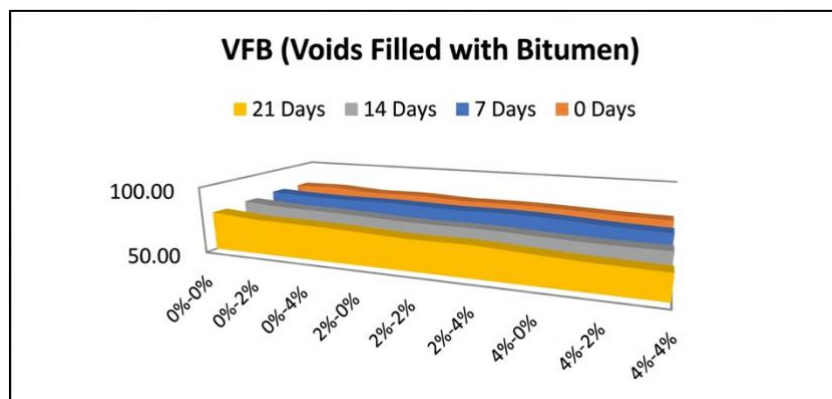


Figure 7. VFB recapitulation of catalyst resin mixture

The test results after twenty-one days of immersion with several variations indicate that none of the Air Voids (VIM) values met the specifications for road pavement, as all exceeded the allowable limit of 3–5%. However, the values of Voids in Mineral Aggregate (VMA), Voids Filled with Bitumen (VFB), Marshall Stability, Flow, and Marshall Quotient were all within the acceptable range according to the 2018 Bina Marga Technical Specifications (Revision 2). A comparison of the VIM, VMA, and VFB values shows that all specimens were unsuitable for pavement application because their VIM values

exceeded 5%, thereby not complying with the 2018 Bina Marga Technical Specifications (Revision 2).

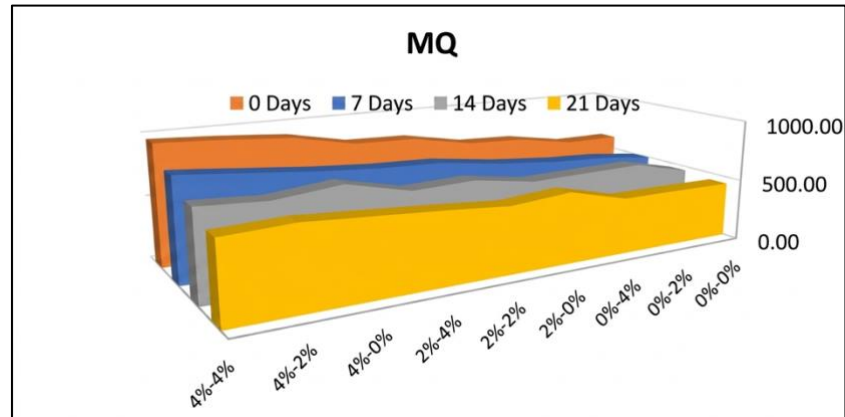


Figure 8. Marshall recapitulation of catalyst resin mixture

The recap of the Marshall test results for specimens with resin and catalyst combinations of 0%, 2%, and 4% (three samples for each composition and immersion period) shows that the mixture generally meets the Bina Marga 2018 Revision 2 technical specifications. Air Voids (VIM) values for 0-day immersion were within the specification range of 3–5%, except for the 4%-resin with 2% and 4% catalyst combinations, which exceeded the limit. After 7 days, similar results were observed, with some variations slightly exceeding 5%. However, after 14 and 21 days of immersion, all samples exceeded the VIM limit, indicating a decline in durability due to prolonged water exposure. In contrast, the Voids in Mineral Aggregate (VMA) and Voids Filled with Bitumen (VFB) parameters consistently met the specification requirements across all variations and immersion periods, with VMA values reaching up to 23.35% and VFB up to 81.78%. Flow values for all samples remained within the standard range (maximum 3.60 mm), while Marshall Stability values were above the minimum requirement, though they tended to decrease slightly with longer immersion. The Marshall Quotient (MQ) also satisfied the Bina Marga specification, with the highest recorded value of 969.10 kg/mm at 0-day immersion and a gradual reduction thereafter (Figure 8). Overall, resin-modified asphalt mixtures exhibited satisfactory short-term performance but showed a reduction in air void stability after 14 and 21 days, highlighting the influence of prolonged immersion on structural integrity. Modification improves initial stability but becomes less effective after long-term moisture exposure. That water-induced stripping and oxidation can significantly alter binder cohesion and aggregate bonding in polymer-modified asphalt.

From a practical standpoint, newer and more intuitive analytical approaches such as visual dashboards, radar charts, or correlation heatmaps could enhance the interpretation of multi-parameter relationships among VIM, VMA, VFB, and stability indices. These tools would provide a clearer and faster way for readers and practitioners to understand how resin and catalyst variations influence pavement performance [22]. Further research is recommended to investigate the microstructural interaction between resin, catalyst, and bitumen using advanced analytical methods such as Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR),

and long-term aging simulations. Such studies could reveal the mechanisms responsible for the observed reduction in stability after extended immersion [23].

The novelty of this study lies in demonstrating that resin–catalyst modification can initially enhance asphalt mixture performance under short-term conditions but becomes less effective after prolonged exposure to water. This finding provides new insight into the time-dependent durability of polymer-modified asphalt mixtures under tropical environmental conditions and contributes to the optimization of sustainable binder modification strategies in Indonesia.

## Conclusion

This study concludes that increasing the resin and catalyst content in Asphalt Concrete–Wearing Course (AC–WC) mixtures immersed in tidal (rob) water raises the Air Void (VIM) values, resulting in larger internal voids and reduced environmental durability. The optimum composition was identified at 4% resin without catalyst after 7 days of immersion, which complied with the 2018 Bina Marga Technical Specifications (Revision 2). Continuous immersion was found to decrease the mixture’s stability, leading to permanent deformation, bleeding, and stripping, thereby weakening the asphalt’s long-term performance. These findings advance the understanding of salinity-resistant asphalt design for coastal environments by highlighting the performance threshold of resin-modified mixtures under saline exposure. Future research should explore advanced binder modification strategies, including nano-reinforcement, surface energy analysis, and resin–salt interaction modeling, to develop more durable and chloride-resistant asphalt materials suitable for sustainable coastal infrastructure.

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