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Moisture Susceptibility and Marshall Stability Characteristics of Concrete Latex-Modified Asphalt Concrete Mixes

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ABSTRACT
Flexible pavements in the moisture-prone Niger Delta region of Nigeria suffer persistent stripping, raveling, and premature strength loss, yet concrete latex, a locally available polymeric additive, remains largely unexplored as a low-cost bitumen modifier for this context. This study evaluates the effect of concrete latex content (0, 2, 4, 6, 8 and 10% by weight of bitumen) on the Marshall mix design properties of asphalt concrete and assesses moisture durability under water immersion periods of 0, 1, 2, 3, 4 and 7 days. Gravel, sand, and asphalt cement sourced from Mile 3 market, Port Harcourt, were characterized per ASTM C136. An optimum asphalt content of 5% was established from trial mixes, and Marshall specimens at each latex dosage were tested for stability, flow, bulk density, air voids, and voids in mineral aggregate (VMA) after progressive water immersion. Marshall Stability rose from 12.78 kN (control) to a peak of 15.83 kN at 6% latex content (a 23.9% improvement) before declining at higher dosages. The 7-day retained-stability ratio improved from 58.5% (control) to approximately 66-67% across latex-modified mixes. VMA decreased by up to 14.5% and bulk density increased by roughly 1.5% at 6% latex, while flow values remained lowest at this dosage across all immersion periods. Concrete latex is an effective, low-cost modifier for improving both the strength and moisture durability of asphalt concrete, with 6% content by weight of bitumen identified as optimum. These findings support its use as a practical strategy for enhancing flexible pavement performance in the Niger Delta and similarly moisture-prone regions.

Keywords: *Concrete latex; asphalt concrete; Marshall stability; moisture susceptibility; flexible pavement; Niger Delta.*

I. INTRODUCTION

Flexible pavements constitute the dominant road infrastructure type across the world, carrying the vast majority of vehicular traffic in both developed and developing economies. Their long-term performance depends critically on the mechanical and durability properties of the asphalt concrete wearing course, which must resist rutting, fatigue cracking, and moisture-induced damage over the design life of the pavement. Globally, the search for cost-effective modifiers that improve binder-aggregate adhesion and reduce moisture susceptibility has driven extensive research into polymer-modified, rubber-modified, and industrial-waste-modified bituminous mixtures. Polymer blends such as styrene-butadiene rubber (SBR) combined with polypropylene have been shown to improve both moisture resistance and rutting performance of asphalt mixtures relative to unmodified controls [1], while crumb rubber and SBR additives incorporated by the wet process have been reported to raise Marshall stability substantially when dosed near an identifiable optimum combination [2]. Latex-based delivery of polymers, in particular, has attracted interest because it improves anti-rutting and anti-fatigue performance relative to particle-based polymer modification, albeit with some trade-off in storage stability at high dosage [3].

In Nigeria, and particularly within the Niger Delta region, the performance of flexible pavements is further compromised by a combination of high annual rainfall, prolonged flooding, high water tables, and heavy axle loading from petroleum-sector logistics traffic. Case studies along the Enugu/Port-Harcourt expressway corridor have attributed premature flexible-pavement failure to poor subgrade soil quality and the absence of adequate drainage provision [4], while flood-prone corridors elsewhere in the Niger Delta, such as Wilberforce Island, have experienced recurrent pavement washouts during seasonal flooding events, underscoring the acute vulnerability of the region's road infrastructure to moisture ingress [5]. Despite this, the adoption of chemical or polymeric modifiers in routine pavement construction within the region remains limited, largely due to the cost and unavailability of imported additives such as styrene-butadiene-styrene (SBS) or styrene-butadiene rubber (SBR) latex.

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Concrete latex, a polymeric emulsion conventionally used as a bonding and waterproofing agent in concrete repair and construction, is locally available in Nigerian building-materials markets at comparatively low cost. Its film-forming and elastomeric properties suggest potential value as a bitumen modifier, improving aggregate coating, reducing binder susceptibility to moisture stripping, and enhancing the cohesive strength of the mastic. However, a review of the pavement engineering literature reveals that most modified-asphalt studies in Nigeria and internationally have focused on waste-derived modifiers (crumb rubber, waste plastics, calcium carbide residue, marble dust) or established polymers (SBS, SBR) [1]-[3], with little to no reported investigation of concrete latex as an asphalt modifier, and none situated within the Niger Delta's specific hydro-climatic context.

This study therefore addresses a clearly identified gap: the absence of research on concrete latex-modified asphalt concrete for road construction in the Niger Delta region of Nigeria. The specific objectives of the study are to: (i) determine the optimum bitumen content for the aggregate blend using the Marshall mix design method; (ii) evaluate the effect of concrete latex content (0-10% by weight of bitumen) on Marshall stability, flow, bulk density, air voids, and voids in mineral aggregate (VMA); and (iii) assess the moisture durability of the modified mixes by subjecting Marshall specimens to water immersion periods of up to seven days and quantifying the resulting loss of stability and volumetric changes.

II. MATERIALS and METHODS

2.1 Materials

All materials used in this study were sourced from local dealers at Mile 3 Market, Port Harcourt City, Rivers State, Nigeria. Gravel was used as the coarse aggregate, sand as the fine aggregate, conventional asphalt (bitumen) cement as the primary binder, and concrete latex as the modifying agent. Table 1 presents the aggregate gradation and the specification limits used to proportion the gravel-sand blend (0.60 gravel : 0.40 sand) in accordance with ASTM C136 [6]. Table 2 presents the physical characterization of the gravel, sand, and asphalt cement, including specific gravity, penetration, viscosity, and softening point, determined using standard Marshall mix design procedures consistent with AASHTO T245 [7] / ASTM D6927 [8] and, where applicable, the Nigerian Federal Ministry of Works and Housing (FMW&H) General Specifications for Roads and Bridges [9].

Table 1. Schedule of Aggregates and Specification Limits for Mix Proportion (ASTM C136)

Sieve (mm)	Specification Limit	% Passing Aggregate A (Gravel)	% Passing Aggregate B (Sand)	Mixture (0.60A+0.40B)
19.1	100	100.0	100.0	100.0
12.7	76 - 92	91.1	100.0	94.7
9.52	64 - 79	43.3	100.0	66.0
4.75	40 - 60	8.6	99.7	45.0
1.18	23 - 37	2.7	87.4	36.6
0.425	7 - 20	1.8	21.2	9.6
0.300	5 - 13	1.8	10.6	5.3
0.075	3 - 8	0.6	0.3	0.5

Table 2. Material Characterization of Aggregates and Asphalt Cement

Property	Gravel	Sand	Asphalt Cement
Specific gravity	2.78	2.66	1.03
Penetration	-	-	66.7
Viscosity (sec.)	-	-	69.3
Softening point (°C)	-	-	49.3

2.2 Mix Design and Concrete Latex Modification

The optimum asphalt content (OAC) was determined by preparing trial Marshall specimens across a bitumen content range of 4-6% and identifying the content that satisfied Marshall stability, flow, and volumetric criteria; an OAC of 5% bitumen (by weight of total mix) was obtained and adopted for all subsequent specimen preparation. Using this OAC, asphalt concrete specimens were then prepared with concrete latex incorporated at six dosage levels 0% (control), 2%, 4%, 6%, 8%, and 10% by weight of bitumen added during the mixing

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stage to promote uniform coating of the aggregate-binder matrix. Specimens were compacted using the standard Marshall hammer (75 blows per face) into 101.6 mm diameter x 63.5 mm height cylindrical moulds.

To evaluate moisture durability, replicate specimens at each latex dosage were submerged in a water bath at room temperature for 0 (unconditioned), 1, 2, 3, 4, and 7 days prior to testing. At the end of each conditioning period, specimens were tested for Marshall stability and flow using a Marshall stability testing machine, while bulk density, percentage air voids, and voids in mineral aggregate (VMA) were computed from the specimen bulk specific gravity, theoretical maximum specific gravity, and aggregate specific gravities, following standard Marshall volumetric procedures.

III. Results and Discussion

3.1 Result of Marshall Stability of Concrete Latex-Modified Asphalt Concrete Mixes

Table 3. Stability of Concrete Latex-Modified Asphalt Concrete Mixes under Moisture Submergence

Concrete Latex (%)	Marshall Stability (KN)					
	Immersion Time (Days)					
	0	**1**	**2**	**3**	**4**	**7**
0	12.78	9.89	9.22	8.07	7.76	7.48
2	12.98	11.32	10.5	9.28	8.92	8.6
4	14.53	12.68	11.76	10.39	9.99	9.69
6	15.83	13.82	12.81	11.32	10.89	10.49
8	15.81	13.78	12.79	11.29	10.79	10.32
10	15.22	13.28	12.31	10.89	10.47	10.09

In Table 3 and Figure 1 below it was observed that the stability of the asphalt concrete mixes continuously decreased with increasing days of immersion up to day 7. At zero-day (unconditioned) immersion, Marshall Stability increased progressively with concrete latex content, from 12.78 kN in the control mix to a peak of 15.83 kN at 6% latex, a 23.9% improvement before declining to 15.81 kN at 8% and 15.22 kN at 10%. This trend is consistent with a two-stage modification mechanism commonly reported for polymer-modified bitumen: at low-to-moderate dosages, the latex film coats the aggregate surface and bridges the bitumen mastic, improving cohesion and load-bearing capacity through mechanical interlocking and increased binder viscosity. Beyond an optimum threshold (6% in this study), excess latex is understood to dilute and partially plasticize the bitumen matrix, reducing internal friction and marginally lowering stability, consistent with the declining trend observed at 8-10%.

Immersion in water produced a consistent reduction in stability across all mixes, reflecting progressive stripping of the bitumen film from the aggregate surface and softening of the mastic under prolonged moisture ingress. However, the rate of this loss was moderated by latex modification: the index of retained stability (IRS), defined as the ratio of 7-day to 0-day stability, was 58.5% for the unmodified control but rose to 66.3-66.7% for all latex-modified mixes (2-10%), with the 4% and 6% dosages recording the highest retained-strength ratios (66.7% and 66.3% respectively). This indicates that concrete latex confers a genuine moisture-resistance benefit independent of its effect on initial strength, most plausibly through improved hydrophobic film continuity around the aggregate that slows water ingress into the binder-aggregate interface

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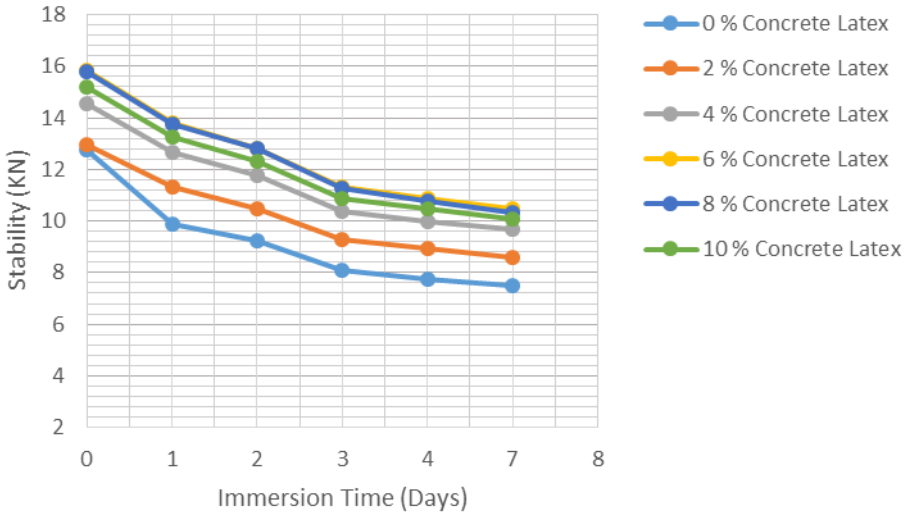

Figure 1: Stability against Immersion Time

3.2 Flow Result of Concrete Latex-Modified Asphalt Concrete Mixes

Table 4. Flow of Concrete Latex-Modified Asphalt Concrete Mixes under Moisture Submergence

Concrete Latex (%)	Flow (mm)					
	Immersion Time (Days)					
	0	1	2	3	4	7
0	3.75	3.92	4.02	4.53	4.68	4.79
2	3.65	3.70	3.76	3.80	3.84	3.86
4	3.54	3.69	3.71	3.73	3.79	3.80
6	3.32	3.52	3.56	3.59	3.67	3.72
8	3.37	3.63	3.69	3.73	3.83	3.89
10	3.49	3.67	3.71	3.83	4.01	4.22

The response of asphalt concrete flow due to immersion of the concretes between 0 - 7 days is presented in Figure 2, it was observed that the flow of the asphalt concrete mixes continuously increased with increasing days of immersion up to day 7. In Table 4, flow values at zero-day immersion decreased from 3.75 mm in the control to a minimum of 3.32 mm at 6% latex content, before rising again at 8% (3.37 mm) and 10% (3.49 mm), mirroring the inverse of the stability trend. A lower flow value at equivalent or higher stability indicates a stiffer, more rut-resistant mix, reinforcing 6% as the mechanically optimum dosage. Flow increased with immersion time for all mixes, consistent with progressive softening and loss of mastic stiffness under moisture exposure; however, the magnitude of increase was smallest for the 6% mix (3.32 mm to 3.72 mm, +12.0%) compared with the control (3.75 mm to 4.79 mm, +27.7%), again pointing to improved moisture resilience conferred by latex modification at the optimum dosage.

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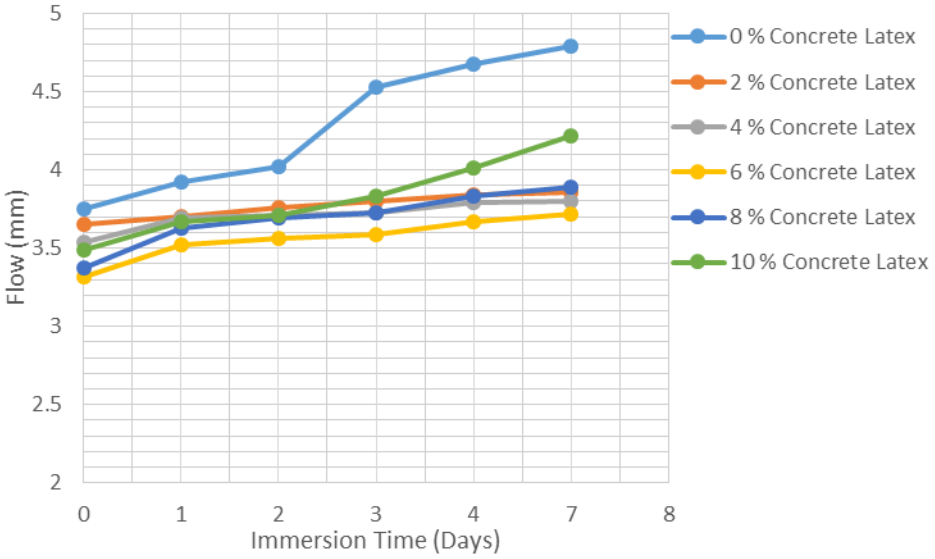

Figure 2: Flow against Immersion Time

3.3 Density Result of Concrete Latex Modified Asphalt Concrete Mixes

Table 5: Density of Concrete Latex Modified Asphalt Concrete Mixes under Moisture Submergence

Concrete Latex (%)	Density (Kg/m^3)					
	Immersion Time (Days)					
	0	1	2	3	4	7
0	2364	2360	2356	2353	2345	2340
2	2379	2373	2365	2360	2356	2348
4	2389	2387	2386	2383	2369	2354
6	2400	2397	2391	2389	2375	2370
8	2390	2386	2383	2378	2370	2365
10	2389	2385	2380	2376	2365	2359

The response of asphalt concrete density due to immersion of the concretes between 0-7 days is presented in Figure 3, it was observed that the density of the asphalt concrete mixes continuously decreased with increasing days of immersion up to day 7. Density increased with latex content up to 6% (2400 kg/m³ at 0-day, versus 2364 kg/m³ for the control, an increase of approximately 1.5%), before declining slightly at 8% and 10%. The increase in density is attributable to improved packing of the aggregate-binder matrix as the latex film fills residual micro-voids, consistent with the corresponding reduction in air voids and VMA discussed below. Density declined modestly with immersion time across all mixes (approximately 1.0-1.3% loss from 0 to 7 days), reflecting minor volumetric expansion or micro-damage associated with water absorption into the mix; this loss was not eliminated by latex modification, indicating that while latex slows moisture-induced strength loss, it does not fully arrest moisture ingress into the compacted mix.

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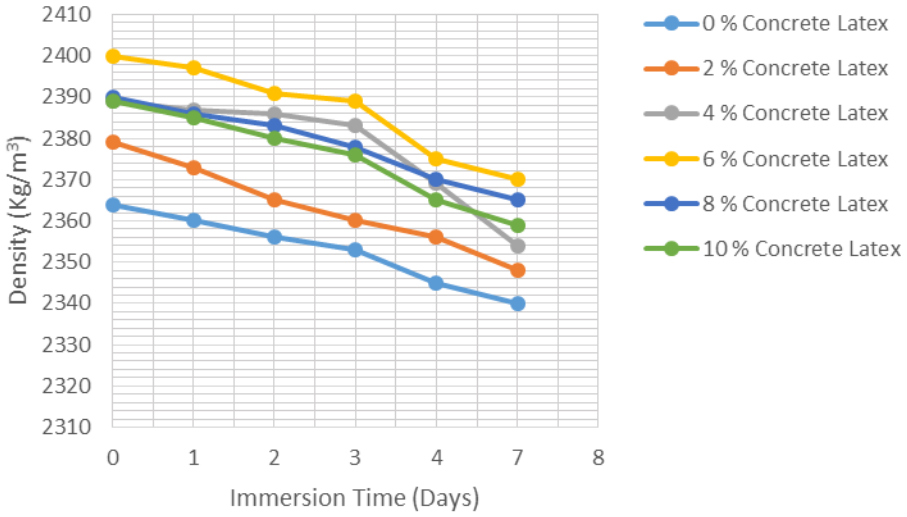

Figure 3: Density against Immersion Time

3.4 Result of Air Voids of Concrete Latex Modified Asphalt Concrete Mixes

Table 6: Air Voids of Concrete Latex Modified Asphalt Concrete Mixes under Moisture Submergence

Concrete Latex (%)	Air Voids (%)					
	Immersion Time (Days)					
	0	1	2	3	4	7
0	4.509	4.519	4.563	4.862	5.042	5.063
2	4.484	4.486	4.488	4.5	4.503	4.51
4	4.314	4.316	4.327	4.37	4.39	4.415
6	3.771	4.01	4.209	4.293	4.304	4.396
8	4.111	4.12	4.291	4.46	4.487	5.217
10	4.394	4.424	4.52	4.609	4.684	6.81

From Figure 4, it was observed that the air voids of the asphalt concrete mixes continuously increased with increasing days of immersion up to day 7. In Table 6, at zero-day immersion, air voids decreased from 4.509% in the control to a minimum of 3.771% at 6% latex content, confirming that latex addition improves aggregate packing and reduces the interconnected void structure through which moisture would otherwise penetrate. Air voids increased progressively with immersion time for all mixes, a change consistent with minor internal swelling or stripping-related void formation. Notably, the 10% latex mix showed an anomalous sharp rise in air voids at day 7 (6.81%, versus 4.684% at day 4), a discontinuity substantially larger than the trend observed for any other dosage. This is most plausibly attributable to localized stripping or moisture-induced disintegration at excessive latex dosage, though it may equally reflect measurement variability in a single (non-replicated) specimen; replicate testing at the 10% dosage under 7-day immersion is recommended before drawing firm conclusions about performance at this upper dosage boundary.

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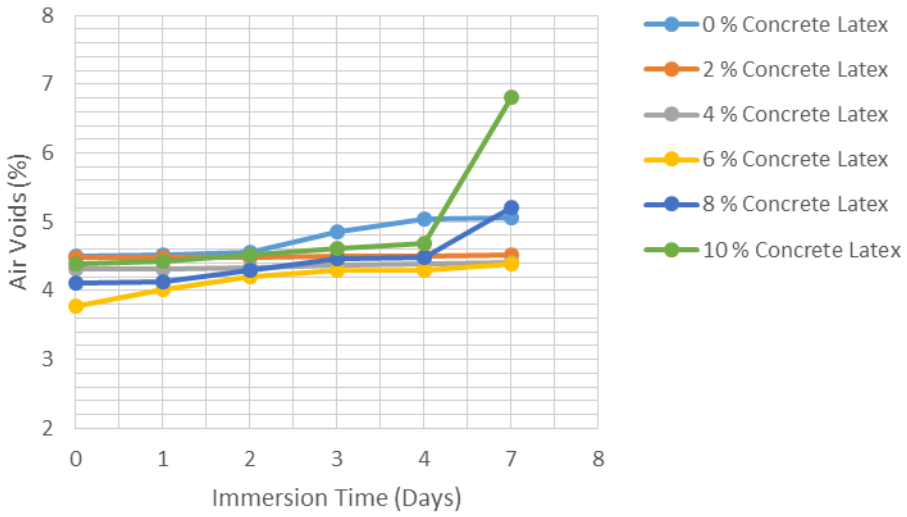

Figure 4: Air Voids against Immersion Time

3.5 VMA Result of Concrete Latex Modified Asphalt Concrete Mixes

The response of asphalt concrete voids in mineral aggregate VMA due to immersion of the concretes between 0-7 days is shown in Figure 5. It can be observed that the air voids of the asphalt concrete mixes continuously increased with increasing days of immersion up to day 7.

VMA fell sharply with the introduction of concrete latex, from 18.013% in the control to 15.401% at 6% latex content (a reduction of 14.5%), before rising slightly at 8% (15.754%) and 10% (15.775%) see Table 7. This substantial reduction indicates that concrete latex is an effective void-filling and aggregate-packing agent, likely due to its fine colloidal particle size and film-forming behaviour within the mastic, which reduces the void space between coated aggregate particles beyond what bitumen alone achieves. All VMA values across latex dosages remained within or close to the ranges typically specified for dense-graded asphalt concrete (13-15% depending on nominal maximum aggregate size), supporting the volumetric adequacy of the latex-modified mixes for wearing-course application, subject to confirmation against the specific FMW&H or Marshall design criteria adopted for the nominal aggregate size used.

Table 7: VMA of Concrete Latex Modified Asphalt Concrete Mixes under Moisture Submergence

Concrete Latex (%)	VMA (%)					
	Immersion Time (Days)					
	0	1	2	3	4	7
0	18.013	18.193	18.264	18.623	18.981	19.339
2	15.984	15. 986	16.058	16.123	16.129	16.175
4	15.544	15.658	15.737	16.075	16.120	16.125
6	15.401	15.600	15.643	15.650	15.714	15.960
8	15.754	15.764	15.831	15.886	15.900	16.647
10	15.775	15.793	15.888	15.906	15.928	17.151

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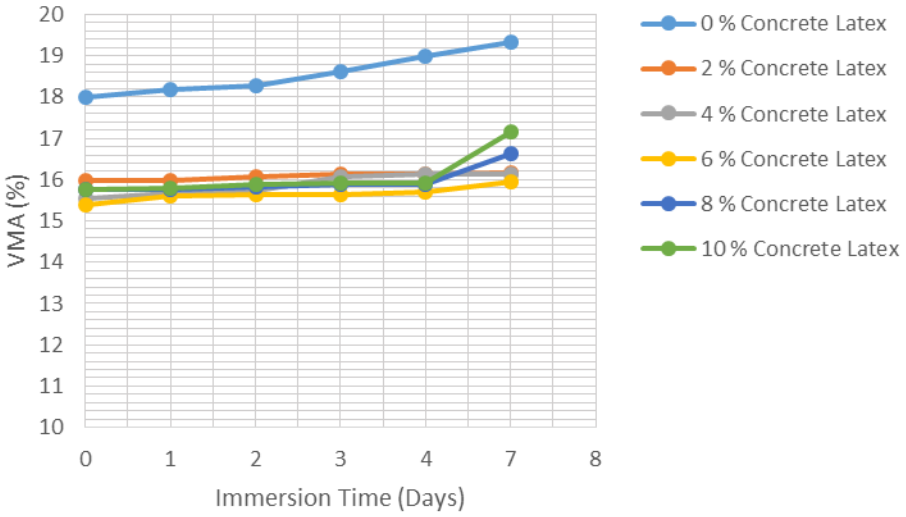

Figure 5: VMA against Immersion Time

IV. DISCUSSION

The stability-enhancing and moisture-resistance benefits observed here are broadly consistent with findings reported for other polymer- and elastomer-modified asphalt systems, such as SBR latex and styrene-butadiene-styrene (SBS) modified mixes, where optimum dosages in the range of 4-6% are frequently reported to maximize stability while avoiding the stiffness loss and workability problems associated with over-dosing [1]-[3]. The present results extend this body of evidence to concrete latex, a modifier not previously reported in the peer-reviewed pavement literature for this application, and situate the finding specifically within the moisture-critical Niger Delta environment [4], [5], where the practical significance of a 66% versus 58.5% retained-stability ratio after seven days of submergence translates directly into a longer service life for surface courses exposed to seasonal flooding and high water tables.

V. CONCLUSION

This study evaluated the effect of concrete latex modification on the Marshall mix design properties and moisture durability of asphalt concrete using locally sourced materials from Port Harcourt, Rivers State, Nigeria. The following conclusions are drawn:

1. Concrete latex is an effective modifier for asphalt concrete, with 6% latex content (by weight of bitumen) identified as the optimum dosage, producing a 23.9% improvement in unconditioned Marshall stability and the lowest flow value relative to the control and all other dosages tested.
2. Concrete latex modification improves moisture durability: the index of retained stability after seven days of water immersion rose from 58.5% (control) to approximately 66-67% for latex-modified mixes, indicating measurably reduced susceptibility to moisture-induced stripping.
3. Latex addition reduced VMA by up to 14.5% and increased bulk density by approximately 1.5% relative to the control, consistent with improved aggregate packing and void-filling by the latex film within the bitumen mastic.
4. Dosages beyond 6% (8% and 10%) showed diminishing or reversing benefits, including an anomalous rise in air voids at 10% latex after seven days of immersion, suggesting an upper practical limit to latex incorporation that warrants further, replicated investigation.

For practicing engineers and pavement agencies in the Niger Delta and similar moisture-prone regions of Nigeria, the findings support the consideration of concrete latex — a low-cost, locally available material — as a practical modifier for wearing-course asphalt concrete in flood-prone or high-water-table corridors, subject to site-specific mix verification.

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