MARSHALL MIX DESIGN FOR COASTAL ROADS IN KERALA

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Abstract - Coastal highways are one of the developing modes of transportation in India. Due to the convenience of operation and maintenance and by considering its low cost and abrasive resistance, asphalt mixtures are commonly used for the construction of coastal roads. Since the coastal highways run near and parallel to the sea, they are always vulnerable to sea water and it is widely known that salinity badly impacts asphalt. Asphaltic pavements which are subjected to the effect of salinity shows reduced cracking resistance, reduced adhesion between binder and aggregates, reduced load bearing capacity, aging etc. and these are mainly due to the migration of salt into the mixture and resulting crystallization effect and other chemical reactions. Though coastal highways are emerging widely in Kerala there is no practical and cost-effective solution for this problem of salinity. A number of researches are conducted to understand the effect but very few are intended for finding a solution. So, in this paper we are using Marshall stability and Retained Marshall stability tests on various samples containing candle wax, natural rubber, and plastic waste as added additives to study the effect of salt water on the load-bearing capacity and flow rate of the sample. Water sample collected from a seashore and a laboratory-prepared salt water sample are used to evaluate the samples. These results are compared with the wet and dry Marshall stability and volumetric properties of sample without any added additives to find a suitable solution to address this problem considering both practicality and cost effectiveness in the form of a modified asphalt mix.

Keywords: Marshall stability, Retained Marshall stability, Candle wax, Natural rubber, Plastic waste.

1.INTRODUCTION

Coastal highway which runs parallel to the coast is one of the major upcoming projects of Kerala. It spreads around 623 kms from Trivandrum to Kasaragod. Bituminous mix is used for the construction of coastal roads as same as that of other roads and highways. Besides from other locations coastal areas are always vulnerable to the effect of salinity in the form of sea water, spraying of salt, fog and mist containing salt etc.

Bituminous mix mainly consists of a bitumen binder, coarse and fine aggregates and filler material. Bitumen is commonly used for the construction of roads around the world due to its convenience in maintenance and operation. Bitumen has gained popularity also due to its low cost compared to other pavement types like concrete pavement with all the same benefits. Bitumen is known for its superior abrasion resistance and flat surface.

But when bitumen is used in coastal areas it is subjected to salinity and it negatively affects the life and properties of bitumen. Bitumen when comes in contact with salt results in aging, reduction in cracking resistance, reduction in adhesion between bitumen and aggregates and an increase in chances of stripping. The effect of salinity which is to be seriously considered is the reduction in binding ability of bitumen as it is the root cause for stripping, cracking and aging. It is the bitumen binder that binds the aggregates together and forms the pavement but when this ability of bitumen is affected it will affect the entire serviceability of pavement.

Fig-1: A burst salt blisters

Fig-2: Water & salt crystals in cracks in a car park

Sea water is mainly composed of sodium chloride (NaCl) and sodium sulphate (Na_2SO_4) and this will chemically react with binder and aggregate and cause problems other than the above discussed ones. The impacts of sea water on bituminous mixes are due to the crystallization effect after the migration of salt from sea water into the mixture.

As the presence of salt in coastal areas cannot be avoided and bitumen cannot be replaced with other materials, it is important to find a solution for this problem. The paper discusses a solution in the form of some additives that can be added to the bituminous mix to counter the effects of salt without any negative impacts to the properties of bitumen as well as to the environment, with ease of availability and cost effectiveness.

The paper mainly investigates the effect of seawater and salinity on the load-bearing capacity and flow value of bitumen mix through the Marshall stability test and Retained Marshall stability test on samples containing the below-mentioned additives under two saline conditions.

1.1 Candle Wax

Wax is a material that is available at a low cost and is almost always available. It is known that wax can be added to bitumen to improve its stiffness in the form of softening points, better penetration, and better binding properties. Candle wax is a simple form of wax that becomes waste material after burning, as candles made from recycled wax are not bright and have an unattractive appearance. So, candle wax having a specific gravity of 0.86 is used in this paper as an additive to study how it affects the load-bearing capacity and flow rate of samples under saline conditions.

Fig-3: Melting of wax

1.2 Natural Rubber

Natural rubber is a material that is readily available in Kerala. It has been used in road construction because of its good resistance to temperature and water penetration, so we can also analyse how natural rubber mixed with bitumen prevents the effect of salt water. The rubber industry in Kerala is near destruction due to the very low market price, but the use of rubber to counter salinity can boost the industry. So, rubber with a specific gravity of 0.96 is used in this paper as an additive to study how it affects the load-bearing capacity and flow rate of samples under saline conditions.

Fig-4: Natural rubber crumps

1.3 Plastic Bottle

Plastic waste is a major threat to our society. It is currently used in road construction as it leads to increased bonding and an increased area of contact between polymer and bitumen. They do not absorb water and have better flexibility, which results in less rutting and less need for repair. Around 20 lakh packaged drinking water bottles are sold per day in India, and as these bottles are not commonly reused, the majority of them end up in dumping yards. So, polyethylene terephthalate (PET)-type plastic bottles with a specific gravity of 1.297 are used in the paper as an additive in the bitumen mix.

Fig-5: Melting of plastic bottle

1.4 Water Samples for Evaluating Sample

All the samples prepared for the paper are evaluated using two water samples. One of them is collected directly from the sea, and the other is prepared in the laboratory. Sea water is collected from Mararikulam Beach in the Alappuzha district of Kerala State. The second one is prepared by diluting 350 gms of table salt per litre of tap water, which is around ten times the salt concentration of sea water. The dilution is made possible by slightly heating the water.

2. Preparation and Testing of Samples
2.1 Materials

Materials needed for the production of samples include crushed aggregate, bituminous binder, filler, and additives. Coarse aggregate and fine aggregate of specific gravity 2.5 and 2.72 respectively are used. VG-30 bitumen of specific gravity 1.02 is used for all the samples. Quarry dust of specific gravity 2.72 is used throughout the experiments as filler material.

2.2 Preparation of Samples

The coarse aggregates, fine aggregates and the filler material should be proportional and mixed in such a way that final mix after blending has the gradation within the specified range with specified gradation of mineral aggregates as per MoRTH 2013 given in Table 1. The required quantity of mix is taken so as to produce a compacted bituminous sample of thickness 63.5 mm approximately.

Approximately 1200 g of aggregates and filler are taken and heated to a temperature of 150^{0}C to 170^{0}C. The compaction mould assembly and rammer are cleaned and kept pre heated to a temperature of 100 to 145^{0}C. The bitumen is heated to a temperature of 150^{0}C to 165^{0}C and the required quantity of bitumen (Optimum binder content) is added to the heated aggregate and thoroughly mixed at a temperature of 150°C to 165°C by hand mixing with trowel. The mix is placed in a mould and compacted by rammer, with 75 blows on either side. The compacting temperature should be minimum 140°C.

Table-1: Aggregate Gradation

Grading	**1**	**2**
Nominal aggregate size	**19mm**	**13.2mm**
Sieve size	**Percentage passing by weight**	**Percentage passing by weight**
26.5mm	100	
19mm	90-100	100
13.2mm	59-79	90-100
9.5mm	52-72	70-88
4.75mm	35-55	53-71
2.36mm	28-44	42-58
1.18mm	20-34	34-48
600µ	15-27	26-38
300µ	10-20	18-28
150µ	5-13	12-20
75µ	2-8	4-10
Binder content percent by weight of total mix	Min 5.2	Min 5.4

The compacted samples with bitumen of grade VG- 30 are allowed to cool to room temperature, the sample height and weight is determined, theoretical density is calculated. The sample is then weighed in air and in water for determining volume and later bulk density. The samples are then transferred into a water bath, kept at 60° C for 30 to 40 minutes. They are then removed, and placed in Marshall test head. Their Stability and flow values are noted. They are corrected for variation from average height. The corrected Marshall stability value of each sample is determined by applying the approximate correction factor, if the average height of the sample is not exactly 63.5mm the correction factors are given in table 2.

Table-2: Correction factors for height

Volume	**Height**	**Correction**
457-470	57.1	1.19
471-482	68.7	1.14
496-508	61.9	1.04
509-522	63.5	1
523-535	65.1	0.96
536-546	66.7	0.93
547-559	68.3	0.89
560-573	69.9	0.86

The same process as described above is used to make the additive-containing samples, and the additives are added at a rate of 6% by weight of the binder content. The additives are added at the same time of mixing of binder with aggregates at the same temperature as that of binder. All additives are added in liquid form.

2.3 Testing of Samples

2.3.1 Softening point

The softening point of bitumen is the temperature at which the substance attains a particular degree of softening under specified conditions of test. The determination of softening point helps to know the temperature up to which a bituminous binder should be heated for various road use applications. The softening point of virgin bitumen and bitumen containing additives are found and compared.

2.3.2 Ductility

The ductility test gives a measure of adhesive property of bitumen and its ability to stretch. In a flexible pavement design, it is necessary that binder should form a thin ductile film around the aggregate so that the physical interlocking of the aggregate is improved. Binder material having insufficient ductility gets cracked when subjected to repeated traffic loads and it provides pervious pavement surface. Ductility of bituminous material is measured by the distance in centimetre to which it will elongate before breaking when two ends of standard briquet sample of material are pulled apart at a constant speed and constant temperature.

Salinity is known to decrease the binding property of bitumen so it is important to test the change in ductility value of bitumen additive mix otherwise the combination will be of no use.

2.3.3 Marshall stability test and Volumetric analysis

Marshall Stability test and volumetric analysis was conducted to determine stability, flow, density and air voids. After 24 hours of air cooling, the dimensions of the samples are recorded and they are submerged in a constant water bath maintained at 60 ^{0}C for 30 to 40 min. The sample is loaded at a constant rate, and loading is applied till the sample fails. The load at the time of failure is noted and is the Marshall value, and the deformation measured at ultimate loading is the Marshall Flow value. The Marshall stability value is not directly shown by the Marshall testing apparatus, but it is shown as proving ring readings. These proving ring readings are multiplied by a factor of 0.0537 to obtain the Marshall stability value. The corrections are applied to the stability values with respect to the thickness of the samples. The properties like theoretical specific gravity (G_t), bulk specific gravity (G_m), air voids, voids filled with bitumen (VFB), and voids in mineral aggregate (VMA) were determined using the following equations:

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}} \quad \text{.... (1)}$$

W_1=Weight of Coarse aggregate G_1=Specific gravity of CA
W_2=Weight of fine aggregate G_2=Specific gravity of FA
W_3=Weight of filler G_3=Specific gravity of filler
W_b=Weight of binder G_4=Specific gravity of binder

$$G_m = \frac{W_m}{W_m - W_w} \quad \text{.... (2)}$$

W_m=Weight of mix in air
W_w=Weight of mix in water

$$V_v = \frac{(G_t - G_m)100}{G_t} \quad \text{.... (3)}$$

G_t=Theoretical Specific gravity
G_m=Bulk specific gravity
V_a=%air voids

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1+W_2+W_3+W_b}{G_m}} \quad \text{.... (4)}$$

V_b= %volume of bitumen

$$VMA = V_v + V_b \quad \text{.... (5)}$$

$$VFB = \frac{V_b \times 100}{VMA} \quad \text{.... (6)}$$

For evaluating the performance of samples under saline conditions, the respective samples are heated in the above-mentioned water samples for 30 to 40 minutes instead of heating them in normal water. That is, two samples from each trial are heated in every sample evaluating water samples and are tested for Marshall stability values and flow values.

Table-3: Specifications for road and bridge works, fifth revision, MoRTH

Percentage air voids (%)	3-5%
Voids in Mineral Aggregate (VMA) (%)	>14%
Voids Filled by Bitumen (VFB) (%)	65-75%
Flow Value (mm)	2-4
Marshall Stability (kN)	>9

2.3.4 Retained Marshall stability Test

A retained Marshall stability (RMS) test was conducted to determine the reduction in the Marshall stability value of samples due to the effect of water. The Marshall samples are immersed in water for 24 hours at 60^{0}C after an air cure of 24 hours and tested for Marshall stability. These samples are termed wet samples (C2) and compared with conventional samples (C1), also called dry samples. RMS is given by the equation

$$\% RMS = \frac{C2}{C1} \times 100$$

.... (7)

C_2=Marshall stability of wet sample
C_1=Marshall stability of dry sample

Retained Marshall test is only conducted on samples without additive and on samples with the most viable additive. For conducting Retained Marshall test samples are kept immersed in respective sample water for twenty-four hours at 60^{0}C after an air curing of twenty-four hours.

2.3.5 Optimum Binder Content (OBC)

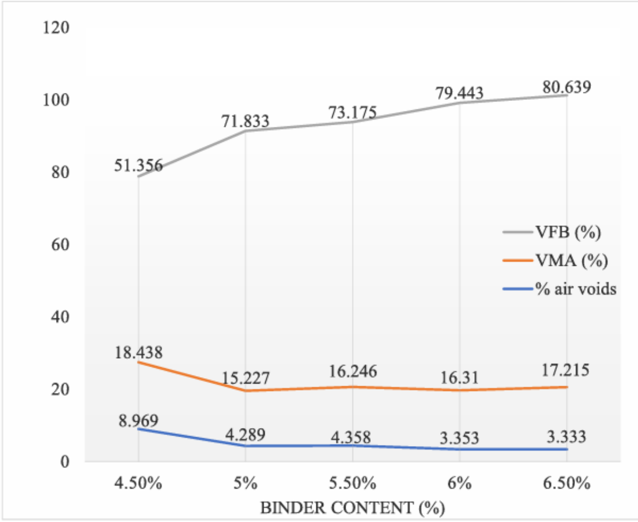
Optimum Binder Content is the amount of binder corresponding to 4% air voids and is represented in percentage by the weight of the total mix. It is obtained by plotting a graph of the percentage of air voids on the y-axis and the binder content on the x-axis.

The Marshall samples were initially cast with binder contents ranging from 4.5 to 6.5% at an increment rate of 0.5% in order to determine the optimum binder content. Marshall Parameters like % air voids, % Voids in mineral aggregate, % Voids filled bitumen, Marshall Stability and flow value were found out. To find the optimum binder content, samples are prepared without adding any additive. The optimum binder content was determined by finding the binder content corresponding to 4 % air voids from graph 1. The Marshall test results for finding optimum binder content are depicted in Table 4.

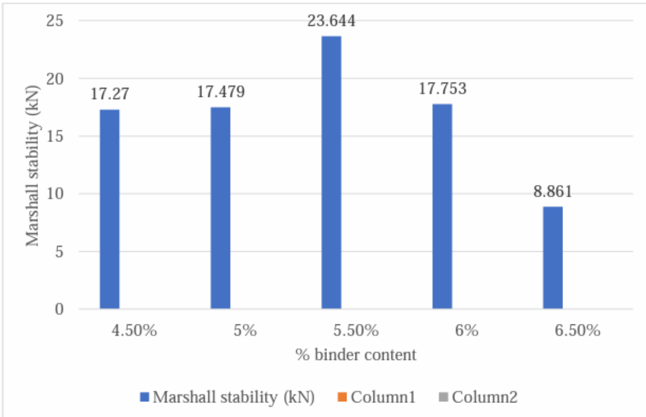
Table-4: Composition to find preliminary OBC

Sample No.	Bitumen Content (%)	Theoretical Specific Gravity (Kg/m³)	Bulk specific Gravity (Kg/m³)	Air voids (%)	VMA (%)	VFB (%)	Corrected Stability (KN)
1	4.5	2464	2243	8.969	18.438	51.356	17.270
2	5	2448	2343	4.289	15.227	71.833	17.479
3	5.5	2432	2326	4.358	16.246	73.175	23.644
4	6	2416	2335	3.353	16.311	79.443	17.753
5	6.5	2400	2320	3.333	17.215	80.639	8.861

For this paper, the optimum binder content corresponds to 4% air voids is 5.678 % and is kept constant for all the samples prepared. Graph 1 shows the variation in percentage of air voids, VMA and VFB with the change in percentage of bitumen content, and the bitumen content corresponding to 4 % air voids is also shown in the graph.



Graph-1: Percentage air voids, VMA, VFB v/s binder content



Graph- 2: Marshall stability v/s binder content

3. Results and Discussions

3.1 Ductility Test

The result of ductility test done on virgin bitumen of grade VG 30 under normal water is shown below.

Table - 5: Ductility test with normal water

Sample No.	Ductility (cm)	Mean (cm)
1	98	
2	100	99

The result of ductility test done on virgin bitumen of grade VG 30 under both saline condition is shown below.

Table -6: Ductility Test with Saline Water

Test environment	1	2	Mean Ductility(cm)
Sea Water	78	64	71
Prepared salt Water	55	72	64

Fig-6: Performing ductility test in lab

Ductility is the ability of a material to have its shape changed without losing strength or breaking. From the above two tables, we can observe that the ductility value of bitumen is reduced as the salt concentration in water increases. A reduction in ductility makes bitumen more brittle. This may be the cause of the reduction in crack resistance of bituminous pavement exposed to saline water.

3.2 Softening Point

The result of Softening point test done on virgin bitumen of grade VG 30 under normal water is shown below.

Table-7: Softening point test with normal water

Test property	Ball 1	Ball 2	Mean
Temperature at which ball touches the bottom (^{0}c)	65	66	65.5

The result of Softening point test done on virgin bitumen of grade VG 30 under both saline condition is shown below.

Table-8: Softening point test with Saline water

Test Environment	Ball 1	Ball 2	Mean
Prepared salt Water	64	63	63.5
Sea Water	65	64	64.5

Fig-7: Softening point test in normal water

Softening point of bitumen is a crucial factor as it indicates the ability of the material to withstand high temperature without significant deformation or damage. Softening point of bitumen affect the temperature susceptibility of bituminous mix. A lower softening point can result in excessive deformation and rutting at high temperature. While a high softening point can lead to cracking and brittle behavior at low temperature. Softening point of bitumen is used to predict the performance of bituminous mix under different temperature conditions.

From above two table we can conclude increase in concentration of salt do not have significant effect on softening point of bitumen.

3.3 Marshall stability test and Volumetric analysis

3.3.1 Marshall test and volumetric analysis done on samples under normal conditions without any additive

Table -9: Marshall test and volumetric analysis results of samples without any additive under normal condition

Sample No.	Theoretical Specific Gravity	Bulk specific Gravity	Air voids (%)	VMA (%)	VFB (%)	Corrected Stability (kN)	Flow value (mm)
1	2.426	2.331	3.916	16.336	76.03	15.724	4.05
2	2.426	2.325	4.163	16.563	74.866	14.982	4.25
Mean	2.426	2.328	4.04	16.45	75.45	15.353	4.15

3.3.2 Marshall test and volumetric analysis done on samples under saline conditions without any additive.

The Marshall stability value of the sample evaluated in seawater conditions shows around a 20% decline in stability value and 20% decline in Flow value when compared with the Marshall stability value of the sample evaluated in normal water conditions. The sample evaluated in laboratory-prepared saltwater conditions shows around a 37% decline in the Marshall stability value and 20% decline in flow value when compared with the Marshall stability value of the sample evaluated in normal water conditions.

This reduction in Marshall stability may be due to the penetration of salt ions into the bitumen. This penetration can cause chemical changes that weakens the bitumen binder. The presence of salt can also increase the rate of oxidation and ageing of the bitumen binder and hence reduces its strength and stiffness. The reduction in Marshall stability indicates that the mixture's ability to resist deformation and cracking is reduced.

Decrease in flow value indicates that the sample becomes brittle. There is decline in flow value of sample tested in both saline conditions compared to that of normal water, which shows that the sample becomes more brittle as concentration of salt in water increases.

Table -10: Marshall test and volumetric analysis results of samples without any additive under saline condition

Sample evaluation condition	Sample No.	Theoretical Specific Gravity	Bulk specific Gravity	Air voids (%)	VMA (%)	VFB (%)	Corrected Stability (kN)	Flow value (mm)
	1	2.426	2.324	4.2	16.588	74.68	11.6	3.29
	2	2.426	2.336	3.71	16.16	77.06	12.888	3.46
Sea water	Mean	2.426	2.330	3.95	16.37	75.87	12.244	3.375
	1	2.426	2.358	2.8	15.37	81.78	10.525	3.249
	2	2.426	2.296	5.36	17.6	69.542	8.807	3.301
Prepared salt water	Mean	2.426	2.327	4.08	16.48	75.66	9.666	3.275

3.3.3 Marshall test and volumetric analysis done on samples under saline conditions with plastic bottles as additive.

Table- 11: Marshall test and volumetric analysis results of samples with plastic additive under Saline conditions

Sample evaluation condition	Sample No.	Theoretical Specific Gravity	Bulk specific Gravity	Air voids (%)	VMA (%)	VFB (%)	Corrected Stability (kN)	Flow value (mm)
Sea water	1	2.42	2.349	2.81	15.29	81.61	19.477	3.35
Sea water	2	2.42	2.321	4.09	16.42	75.1	20.726	2.7
	Mean	2.42	2.335	3.45	15.85	78.35	20.102	3.025
Prepared salt water	1	2.42	2.36	2.36	14.89	84.17	15.98	2.8
Prepared salt water	2	2.42	2.32	4.13	16.46	74.88	11.709	2.11
	Mean	2.42	2.34	3.245	15.68	79.53	13.844	2.455

The Marshall stability value of the sample with plastic additive evaluated in seawater conditions shows around a 64% increase in stability value and a 10% decrease in Flow value. In laboratory-prepared saltwater it shows around a 43% increase in the Marshall stability value and 25% decrease in Flow value, when compared with Marshall stability and flow value of the sample without additive evaluated under both saline conditions. The increase in Marshall stability value in the presence of plastic additive even in saline environment may be due to the increase in stiffness of the mix. Certain plastic has high stiffness and which have ability to increase stiffness of bitumen mixes, leading to higher stability. Increase in stability may be also due to the ability of plastic to improve the cohesion of bitumen mix. An increase in cohesion can lead to better bonding and higher stability. Plastic can also improve the resistance of bituminous mixtures to moisture damage by reducing the amount of water that penetrates the mix.

The reduction in flow value of a bitumen mix containing plastic may be due to the fact that plastic has the ability to make the bituminous mix stiffer. When the rigidity of the mix increases the deformation is decreased and flow value is also decreased.

3.3.4 Marshall test and volumetric analysis done on samples under saline conditions with candle wax as additive.

Table-12: Marshall test and volumetric analysis results of samples with candle wax under Saline conditions

Sample evaluation condition	Sample No.	Theoretical Specific Gravity	Bulk specific Gravity	Air voids (%)	VMA (%)	VFB (%)	Corrected Stability (kN)	Flow value (mm)
Sea water	1	2.409	2.249	6.642	18.592	64.275	7.733	4.3
Sea water	2	2.409	2.180	9.506	21.089	54.924	8.248	4.7
	Mean	2.409	2.214	8.074	19.840	60	8	4.5
Prepared salt water	1	2.409	2.169	9.963	21.487	53.632	6.143	3.2
Prepared salt water	2	2.409	2.185	9.298	20.907	55.527	6.443	3.8
	Mean	2.409	2.177	9.63	21.197	54.579	6.3	3.5

The Marshall stability value of the sample with wax additive evaluated in seawater conditions shows around a 35% decrease in stability value and 33% increase in Flow value. In laboratory-prepared saltwater it shows around a 35% decrease in the Marshall stability value and 7% increase in Flow value, when compared with Marshall stability and flow value of the sample without additive evaluated under both saline conditions.

Most of the result including Marshall stability is not as per MoRTH specification. The reduction in Marshall stability value may be due to the low melting point of candle wax typically made from paraffin. During the Marshall stability test sample is tested to high temperature around 600C. The wax within the mixture will likely soften and melt. This softening can lead to a loss of cohesion and overall strength. The melted wax can act as a lubricant, reducing the friction between aggregate particle and the bituminous binder. This lubricating effect can result in reduced stability. Wax has low adhesion property with bituminous binder so the presence of candle wax in the mixture can hinder the proper addition between the aggregate particles and the binder, which can also reduce stability. The lubricating effect of wax is the reason for increase in air voids.

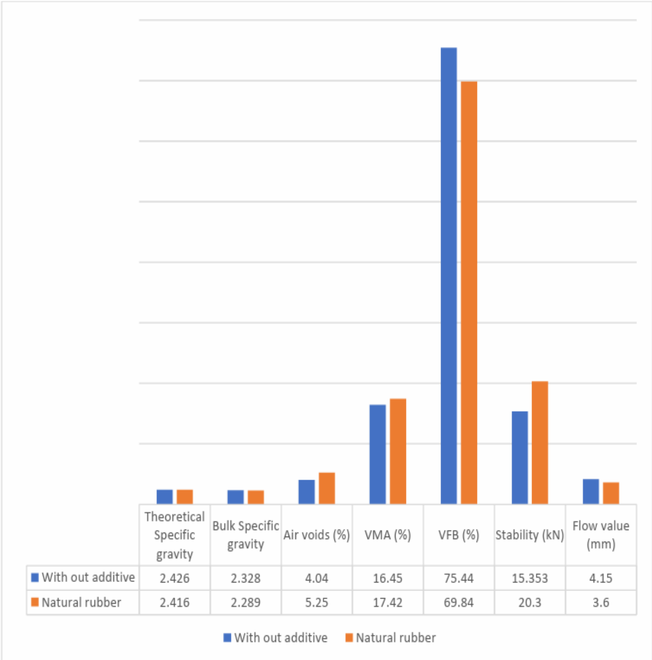
3.3.5 Marshall test and volumetric analysis done on samples with natural rubber as additive.

Table-13: Marshall test and volumetric analysis results of samples with natural rubber

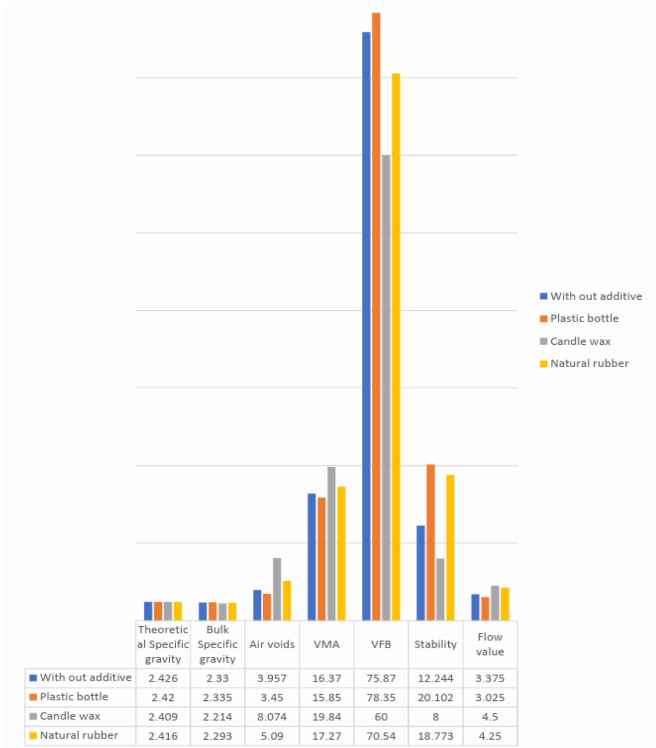
Sample evaluation condition	Sample No.	Theoretical Specific Gravity	Bulk specific Gravity	Air voids (%)	VMA (%)	VFB (%)	Corrected Stability (kN)	Flow value (mm)
Sea water	1	2.416	2.287	5.34	17.49	69.48	18.988	4.3
Sea water	2	2.416	2.299	4.84	17.06	71.61	18.559	4.1
	Mean	2.416	2.293	5.09	17.27	70.54	18.773	4.25
Prepared salt water	1	2.416	2.29	5.2	17.37	70.05	10.31	4.15
Prepared salt water	2	2.416	2.31	4.39	16.66	73.67	10.16	5.15
	Mean	2.416	2.3	4.8	17.01	71.86	10.235	4.65
Normal water	1	2.416	2.287	5.34	17.49	69.48	19.7	3.55
Normal water	1	2.416	2.291	5.17	17.34	70.2	20.9	3.65
	Mean	2.416	2.289	5.25	17.42	69.84	20.3	3.6

The Marshall stability value of the sample with natural rubber additive evaluated in seawater conditions shows around a 54% increase in stability value and 26% increase in flow value. In laboratory-prepared saltwater it shows around a 6% increase in the Marshall stability value and 40% increase in flow value, when compared with Marshall stability and flow value of the sample without additive evaluated under both saline conditions. In normal water Marshall stability value with natural rubber increases up to 32% but flow value is decreased up to 13%, when compared with samples without any additive tested in normal water.

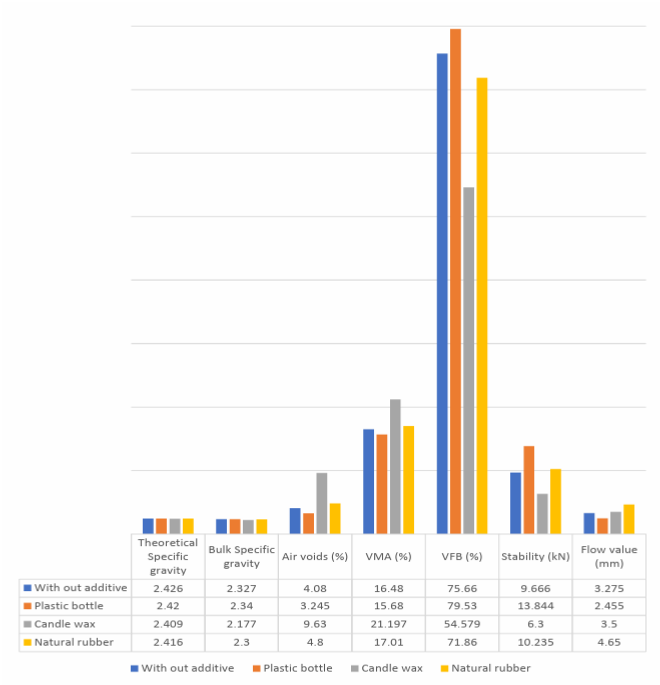
The increase in Marshall stability value may be due to the property of natural rubber to improve binder aggregate adhesion, improved adhesion promotes better bonding which leads to increased stability. Natural rubber has the ability to enhance resistance to deformation by acting as a reinforcing agent and by improving stiffness and elasticity of binder, this increased resistance to deformation can also result in increased stability. Natural rubber increases the elasticity and flexibility of the bituminous binder which improves the stability. Natural rubber can enhance the cohesive strength of bituminous binder. Natural rubber being hydrophobic can repel water and prevent its penetration into the mixture, this improved resistance to the moisture damage can enhance the overall stability of sample in saline condition.



Graph-3: Result obtained in normal water



Graph-4: Result obtained in sea water



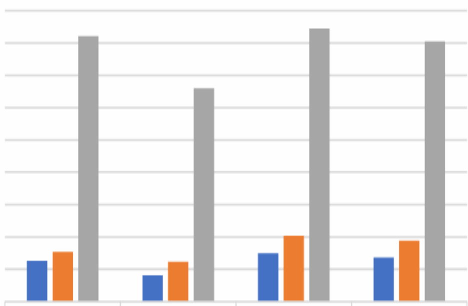
Graph-5: Result obtained in prepared salt water

3.3.6 Retained Marshall test done on samples

Table-14: Percentage RMS values

Sample	Stability conditioned (kN)	Stability controlled (kN)	Percentage RMS
Without additive tested in normal water	12.609	15.353	82.13
Without additive tested in sea water	8.076	12.244	65.96
With natural rubber tested in normal water	17.13	20.3	84.40
With natural rubber tested in sea water	15.10	18.773	80.44

The limiting value of the percentage RMS is 80%. When samples are tested in normal water with rubber as an additive, they show an increase of 2.27% RMS compared with normal water without additive. When samples are tested in sea water with rubber as an additive, it shows an increase of 14.48% RMS compared with sea water without additive. Samples tested in sea water without additives show an RMS value of 65.96, which is less than the limiting value. From these results, we can conclude that the percentage RMS can be improved by adding rubber as an additive. Natural rubber, being hydrophobic, can repel water and prevent its penetration into the mixture; this improved resistance to moisture damage may be the reason for an increase in RMS value.



	Without additive in normal water	Without additive in sea water	Natural rubber in normal water	Natural rubber in sea water
Stability Conditioned (kN)	12.609	8.076	14.98	13.611
Stability Controlled (kN)	15.353	12.244	20.3	18.77
Percentage RMS (%)	82.13	65.96	84.4	80.44

Graph-6: Result of Retained Marshall stability

4. CONCLUSIONS

From the results obtained, it is concluded that the ductility value of bitumen in a saline environment is decreased, and hence the cracking resistance is also decreased. The value of the softening point is not much affected by salinity. The binding property of bitumen is disturbed due to the migration of salt molecules into the mix. The Marshall stability of bituminous mix is decreased as cracking resistance and binding properties of bitumen are decreased. It is also identified that the reduction in Marshall stability increases with an increase in salt concentration. The flow value is observed to be decreasing, which indicates that the sample becomes more brittle.

Three additives were tested to determine their ability to counter the effect of salinity in bituminous mixes, and it was found that the incorporation of candle wax in its pure form is not evident as the stability and volumetric properties are not under limits as per MoRTH specification. Use of candle wax in its pure form is not feasible as its melting point is around 40^0C. Due to low melting point of candle wax it may melt within the Marshall sample and can cause reduction in stability and reduced adhesion between aggregates. Incorporation of plastic and rubber improves the Marshall stability values even under saline conditions and all volumetric properties are under limits as per MoRTH specification.

The addition of plastic and rubber has the ability to improve the adhesion between aggregates. Hence, the addition of both plastic and rubber can solve the major effect of salinity, which is a reduction in the binding property of bitumen. The addition of waste plastic bottles is more economical, and it helps reduce plastic waste to a great extent. But it is not an environmentally friendly solution, as burning plastic bottles to get liquified plastic is a serious threat to the environment. Liquefication of natural rubber also causes air pollution; however, burning plastic tends to produce a wider range of toxic emissions and volatile organic compounds. These emissions from plastic combustion can be more harmful to human health and the environment than those from burning natural rubber.

- ❖ The Marshall stability value of the sample with natural rubber additive evaluated in seawater conditions shows around a 54% increase in stability value, when compared with Marshall stability of the sample without additive evaluated under both saline conditions.

- ❖ The RMS values of rubber added sample is 84.4% and 80.44 in normal and sea water respectively

- ❖ In laboratory-prepared saltwater it shows around a 6% increase in the Marshall stability value, when compared with Marshall stability of the sample without additive evaluated under both saline conditions.

- ❖ In normal water Marshall stability value with natural rubber increases up to 32%, when compared with samples without any additive tested in normal water.

As per the experiments and results, natural rubber is concluded to be the best additive among the three studied under this project. 6% natural rubber by weight of the bitumen is sufficient for better results, so this can be incorporated into the bituminous mix design. It is suitable to be used for the ongoing coastal highway project in Kerala in order to counter the effect of saline water on bituminous pavement. This project can be further extended with more economical and environmentally friendly materials. More advancement in technologies for the liquefaction of natural rubber or plastic with fewer effects on the environment can further improve the reliability of the project.

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