INVESTIGATION ON BITUMEN ASPECTS IN MODIFIED FLEXIBLE PAVEMENT AND ITS CHARACTERIZATION IN HIGHWAY CONSTRUCTION

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Abstract - The severity of rutting, cracks, ravelling, and edge drops on roads has been on the rise in recent years, attributed to heavy traffic, high tyre pressure, and large wheel loads. There have been and will be many more efforts to strengthen and prolong the life of roads by enhancing the structures of flexible pavement. To enhance the bitumen's binding capability, many additives are being added. Bitumen is being combined with various polymers to create polymer modified bitumen. Coating the heated aggregates with polymer and then mixing them with hot bitumen is the procedure. Flexible pavement is made using this combination. The procedure is environmentally benign. Only polymer waste products, such as old plastic bags, cups, foams, etc., are used. Since this procedure simply requires coating aggregate, it is easy to include a greater amount of polymer, say 15-20%. By using waste polymers as a replacement for bitumen, this approach helps to cut consumption by 15-20%. As a result of the higher bonding caused by the polymer covering, the bituminous mix's binding strength is enhanced by 50-100%. The test results from specific areas with varying climates, temperatures, rainfalls, and traffic volumes show that these plastic roads are holding up well and showing no signs of damage like ravelling, rutting, or cracking. Plastic tar road, if approved, would improve India's roads and eliminate the need to properly dispose of polymer waste; an area of 3,750 square metres necessitates at least 1 metric tonne of polymers. India could save a lot of bitumen and put all that polymer waste from polypropylene (PP), polyethylene (PE), and polystyrene (PS) to good use if its roads were built with plastic tar. The author hopes and suggests that the method be implemented throughout the whole country of India as soon as possible, paving the road for Green India.

***Key Words*:** *Polypropylene, Flexible pavement, coating aggregate, Eco-friendly, Plastic wastes, Bitumen and Marshall Stability Test.*

1. INTRODUCTION

In the past, geotechnical engineers have used grouts made of cement to fix problems with foundation performance, such making underground soils more watertight, filling cracks, or strengthening weak soils or rock masses. According to Mozumder, Laskar, and Hussain (2018) and Rosquoët et al. (2003), grouting is a technique used in geotechnical engineering to increase the strength of soil by injecting a solution into the layers of soil underneath that include holes or voids. Cementations grout that is both strong and long-lasting, as well as easily permeable, is not easy to make. Fluidity, strength, impermeability, corrosion protection, sulphate resistance, and sometimes frost resistance are all important properties of a high-performance cementations grout. The in-situ conditions and the grouting objective dictate the mixing method of the several components that make up grouts[1]. Due to the presence of plasticizers, waste plastic has the most detrimental influence. Plasticizers are added to plastics to make them more malleable and easier to work with. However, as they do not establish a covalent link with plastic, they may readily leak into the environment. Due to its buoyant nature, plastic ends up floating aimlessly in the ocean. Over time, it builds up in five distinct patches, the largest of which is the Great Pacific Garbage Patch, which is located in subtropical waters between Hawaii and California. While incineration performs a good job of reducing trash volume, it does not eliminate it entirely; a residue is still left behind. In order to back up this claim, thermogravimetric analysis (TGA) was carried out on many typical plastic waste items, including LDPE plastic packaging, HDPE shampoo bottles, PP phenyl bottles, and PVC pipes.

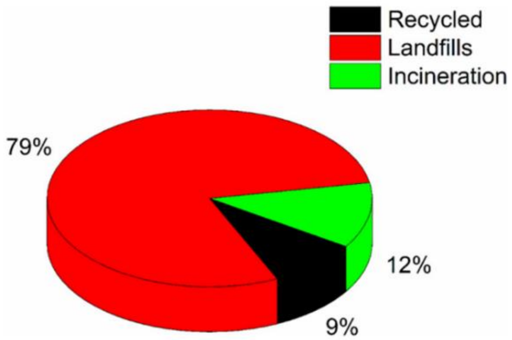


Fig -1: **Pie chart of locations for plastic waste**

1.1 Flexible Pavement

According to Gautam et al. (2018), 95% of the world's roads are made of flexible pavement. However, these pavements can fail due to issues such as stripping, potholes, fatigue cracks, rutting, overweight trucks, etc. (Behiry, 2012)[14]. Additionally, a lot of resources are needed for the maintenance of these pavements, such as the addition of anti-stripping agents (Hossain et al., 2012). As seen in Figure 3, flexible pavement consists of four layers: subgrade, subbase, base, and surface. The elements that determine the thickness of each layer of pavement include the weight that the pavement is expected to sustain, the state of the region where the pavement is being built, and the materials that are used in each layer. The base layer, the second-to-last layer, is responsible for carrying the pavement's weight and is composed of high-quality aggregates to ensure its rigidity (Gautam et al., 2018). As the surface layer that comes into direct touch with traffic, the top layer must be able to resist its load while staying within the elastic limit.

1.2 Surface Layer

The aggregates and binder that make up the bituminous mix (BM) are crushed into the pavement to create the surface layer, which is one of the two main components of the pavement. Pavement with this layer will be more resilient and able to return to its former shape once a weight is lifted, extending the pavement's useful life[18]. To have a high-quality pavement its components need to possess certain characteristics like gaps in aggregate gradation will lead to the porous mix, which can easily get damaged early by seeping and traffic loading, so there must be no gap in gradation; in the same way, morphology, physical and chemical properties of aggregates can also affect BM properties (Fang et al., 2019)[19].

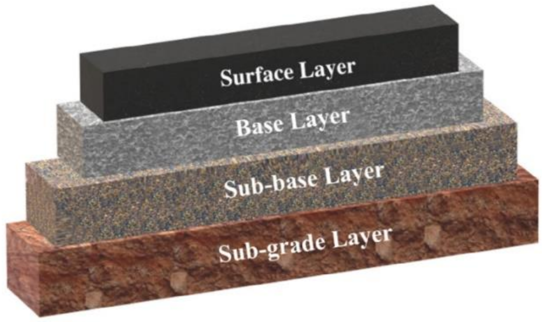


Fig -2: **Layers of Flexible pavement**

2. METHODOLOGY AND OBJECTIVES

A detailed study on the construction of the roads and subsequently on performance of these roads is the need of the hour. The coating of polymers over aggregate improved not only the quality of the road but also the quality of aggregate. A detailed scientific analysis based on physical and chemical properties is being attempted in this work. To ascertain physical properties of polymer coated aggregate, the following tests were carried out[22].

2.1 Objectives

- To study the pure bitumen and modified bitumen Consistency test.
- To carry out different tests on recovered bitumen.
- To study the physical properties of polymer coated aggregate.

2.2 Ductility Test

The ductility of bituminous materials is determined by their elongation-to-break distance in centimetres. It is crucial that the binder be made of ductile thin films around the aggregates when bituminous binders are employed in the production of flexible pavements. The ductility may be defined as the maximum length that a normal bitumen briquette can be stretched before breaking, measured in centimetres. The test is carried out in a temperature range of 27o to 5^{O}c with a pulling rate of 50 ±2.5 mm/min. Tools needed for this test include a thermometer, a water bath, a testing equipment, and a ductility test mould. When any of these variables is changed, the ductility value changes dramatically. Testing temperature, rate of pulling, briquette cross-sectional area, pouring temperature, and briquette placement level[23].

2.3 Softening Point Test

The point in time when, under controlled laboratory conditions, a material softens to a certain degree. The temperature at which the binder undergoes a phase shift was determined using the softening point. A thermometer, a beaker, a stirrer, a ring and ball device, and a ball guide are all necessary components of this experiment[24].

2.4 Viscosity Test

Fluid viscosity is one of the fluid's properties that may be tested. One way to do this is to set the test circumstances so that 50cc of the substance must flow from a cup through a certain aperture in a given amount of time at a given temperature. Tar viscometer, cup, valve, water bath, sleeve, stirrer, curved shield, receiver, and thermometers are the devices used in this test[25].

2.5 Penetration Test

How far a standard needle can go into a bituminous material vertically under controlled circumstances of temperature, load, and duration is called its penetration. This measurement is expressed in millimetres. There are many different kinds and grades of bituminous materials. The following items are used in this experiment: a container, a needle, a water bath, a transfer dish, probe, a thermometer, and a timer. When evaluating bitumen for a grade, the penetration test is the one most often used. A variety of penetration grades and bitumen types are used, 80/100 depending on the weather and the kind of building. Bitumen indicates a penetration value between eighty and one hundred.The penetration levels of different[26].

Fig -3: **Moulds for Ductility Test**

Fig -4: **Ductility Testing Machine**

Fig -5: **Assembly for Softening Point Test**

Fig -6: **Assembly for Viscosity Test**

Fig -7: **Weight of Aggregate for BC (PMB 76-10)**

3. PROCESS METHODOLOGY

At first, the aggregate mix was prepared as per IRC specification and then heated in the cylindrical drum to 170 □C. It was then transferred to the puddling compartment where polymer waste (size between 1.6mm and 4.75mm) was added. As the temperature of the aggregate was around 170 □C and the softening temperature of polymer waste is around 135 □C, the polymer waste got softened and got coated over the aggregate within 30 to 60 seconds. Immediately the hot bitumen 60/70 grade (□ 160□C) was added and mixed in the puddling chamber. The bitumen got coated over the aggregate. As the polymer and the bitumen were in liquid state they got mixed well. The mixture was transferred to the road and it was spread and compacted using 8 Ton rollers.

In this process, the polymer waste was mixed quantitatively with the aggregate using a mechanical device before the addition of bitumen. Central Mixing Plant helps to have better control of temperature and better mixing of material and thereby enabling to have a uniform coating. The material collected at the tipper was uniform and had a temperature of 140 ºC. This was transported to the spot and road was laid using 'pavers' and 8 Ton roller. The spreading was good and the laying was easy. During the process the materials got mixed.

The waste polymer which was collected from the municipal solid waste was segregated and cleaned. The cleaned polymer was shredded in to small pieces of 1.6 mm to 4.75 mm size. The aggregates to be used in the pavement are heated up to 170ºC as per IRC code, at mini hot mix plant or central mixing plant and transferred to the mixer compartment. Shredded waste polymer was added to the hot aggregates and mixed thoroughly.

The flow chart detailing the process of polymer coated aggregate bituminous mix is shown in Fig.8. Cleaning process of waste polymers, shredding waste polymers, heating the aggregates in mini hot mix plant, transferring aggregate to mixing chamber, adding waste polymers to hot aggregates and adding bitumen over polymer coated aggregates

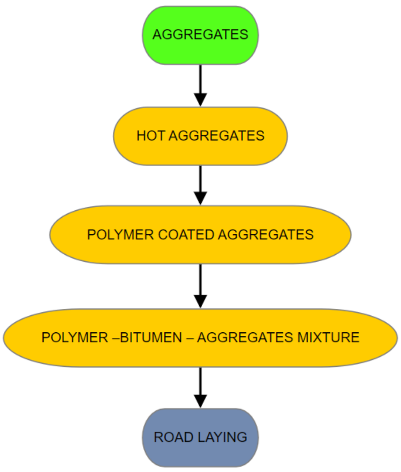


Fig -8: **Flow Chart Showing the Dry Process of PCA Bituminous Mix**

4. PROPERTY EVALUATION OF MATERIALS

Aggregates were collected at four different corners of Nellore Samples for testing were collected as per specifications. Sample I and II were collected from the quarries, which are source of aggregate for road work. Sample III and IV were chosen from the waste obtained in granite quarry where the granite is used for making granite tiles. Large quantities of this waste are available which can be made useful for pavement construction. Basic analyses of these four samples were carried out and the results are tabulated[3].

Table -1: Physical Requirements of coarse aggregates for bituminous carpet (MORTH Specifications)

Property	Test	Specification
Cleanliness	Grain size analysis[1]	Max 5% passing 0.075mm sieve
Particle Shape	Flakiness and Elongation Index[2]	Max 30%
Strength	Los Angeles Abrasion Value[3]	Max 40%
	Aggregate Impact Value[3]	Max 30%
Durability	Soundness[4] Sodium Sulphate	Max 12%
	Magnesium Sulphate	Max 18%
Water Absorption	Water Absorption[5]	Max 2%
Stripping	Coating and Stripping of Bitumen Aggregate Mixtures[6]	Minimum retained coating 95%
Water Sensitivity[7]	Retained Tensile Strength	Min 80%

Due to the movement of traffic, the road stones used in the surface course are subjected to the wearing action at the top. Hence, the road stones should be hard enough to resist the abrasion due to traffic. The principle of Los Angeles (L.A.R) abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and the steel balls used as abrasive charge[4].

A common test used to characterize abrasion resistance is the Los Angeles (L.A.) abrasion test. For the L.A. abrasion test, the portion of an aggregate sample retained on the 1.70 mm (No. 12) sieve is placed in a large rotating drum that contains a shelf plate attached to the outer wall. A specified number of steel spheres are then placed in the machine and the drum is rotated for 500 revolutions at a speed of 30 - 33 revolutions per minute (rpm). The material is then extracted and separated into material passing the 1.70 mm (No. 12) sieve and material retained on the 1.70 mm (No. 12) sieve. The retained material (larger particles) is then weighed and compared to the original sample weight. The difference in weight is reported as a percent of the original weight and called the percent loss. LAR value should be less than 30 percent for pavements. Values up to 50 percent are allowed in base course and Water Bound Macadam (WBM)[5].

It is used to evaluate the toughness of stone or the resistance of the aggregate to fracture under repeated impacts. It indicates a relative measure of resistance of aggregate to impact, which has a different effect than the resistance to gradually increasing compressive stress.

The aggregate impact-testing machine consists of a metal base under cylindrical steel cup of internal diameter 102 mm and 50mm height[6].

A metal hammer of weight 13.5 to 14 kg having a free fall height of 380mm is dropped on the aggregates placed in the cup. The aggregate specimen passing 12.5mm sieve and retained on 10mm sieve is filled in the cylindrical measure in 3 layers by tamping each layer by 25 blows. The aggregates subjected to 15 blows and the crushed aggregates are sieved on 2.36 mm sieve. The aggregate impact value is the percentage of fine to the total weight of the sample[7].

The aggregate impact value should not exceed 30 % for use in wearing course of pavements. Maximum permissible value is 35% for bituminous macadam and 40 % for WBM.

Soundness test is intended to study the resistance of aggregates to the action of weather, by conducting accelerated weathering test cycle. The resistance to disintegration of aggregate is determined by using saturated solution of sodium sulphate or magnesium sulphate[8].

The average loss in weight of aggregates to be used in pavement construction for 5 cycles should not exceed 12 % when tested with sodium sulphate and 18 % when tested with magnesium sulphate[9].

It is the percentage by weight of particles whose greater dimension or the length is greater than one and four fifth or 1.8 times the mean diameter of the aggregates. This test is not applicable to size smaller than 6.3 mm. The sample are sieved through a set of sieve and separated into specified size ranges, from the sample of aggregates two hundred numbers of aggregate samples are tested using a standard gauge to separate elongated aggregates; they are passed through the appropriate length gauge with the longest side in order to separate the elongated particles. The gauge length is 1.8 times the mean size of aggregate. The portion of elongated aggregate having length greater than specified gauge from each range is expressed as percentage of total weight of the sample for test, indicates its elongation index. It is desirable that the elongation index of aggregates used in road construction is less than 15 percent[12].

Flat and elongated particles can cause HMA problems because they tend to reorient and break under compaction. Therefore, they are typically restricted to some maximum percentage (WSDOT 2008).

Table -2: Laboratory test results of plain aggregate of Sunshine Stone Crushers Quarry, Nellore.

S. No	Details / Particulars	Units	Plain Aggregate	MORTH Specifications
1	LosAngelesAbarasionValue(BGrade)	%	37	30
2	Impact Value	%	25.4	30
3	Soundness Value	%	6	12
4	Combined Index Value	%	29.9	30
5	Crushing Value	%	25.9	30
6	Water Absorption Value	%	0.52	2
7	Specific Gravity	--	2.904	2.5-2.9

Table -3: Laboratory test results of plain aggregate of Sri Gayatri Stone Crushers Quarry, Nellore.

S. No	Details / Particulars	Units	Plain Aggregate	MORTH Specifications
1	Los Angeles Abarasion Value (B Grade)	%	25	30
2	Impact Value	%	29.25	30
3	Soundness Value	%	7	12
4	Combined Index Value	%	13	30
5	Crushing Value	%	23.4	30
6	Water Absorption Value	%	0.57	2
7	Specific Gravity	--	2.643	2.5-2.9

Table -4: Laboratory test results of plain aggregate of NKC Stone Crusher Quarry, Nellore.

S. No	Details / Particulars	Units	Plain Aggregate	MORTH Specifications
1	Los Angeles Abarasion Value (B Grade)	%	27.5	30
2	Impact Value	%	39.3	30
3	Soundness Value	%	10	12
4	Combined Index Value	%	8.9	30
5	Crushing Value	%	29.9	30
6	Water Absorption Value	%	0.45	2
7	Specific Gravity	---	2.659	2.5-2.9

Table -5: Laboratory test results of plain aggregate of Southern Rocks and Minerals Pvt.Ltd Quarry

S. No	Details / Particulars	Units	Plain Aggregate	MORTH Specifications
1	Los Angeles Abarasion Value (B Grade)	%	44	30
2	Impact Value	%	33	30
3	Soundness Value	%	9	12
4	Combined Index Value	%	13.14	30
5	Crushing Value	%	29.4	30
6	Water Absorption Value	%	0.51	2
7	Specific Gravity	--	2.66	2.5-2.9

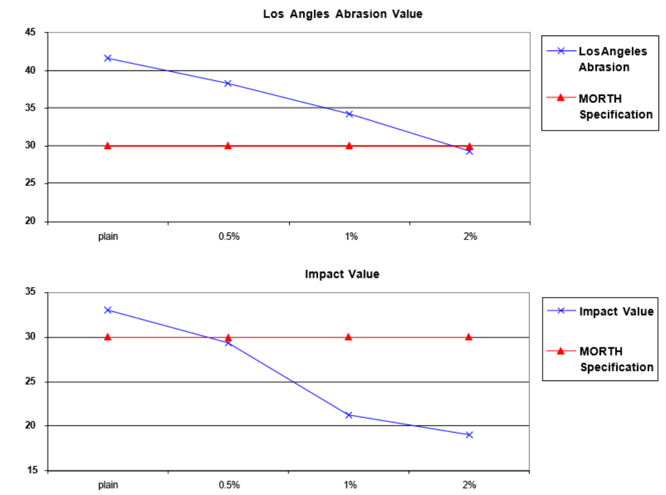


Fig -9: (a) Los Angle Abrasion Value, (b) Impact Value

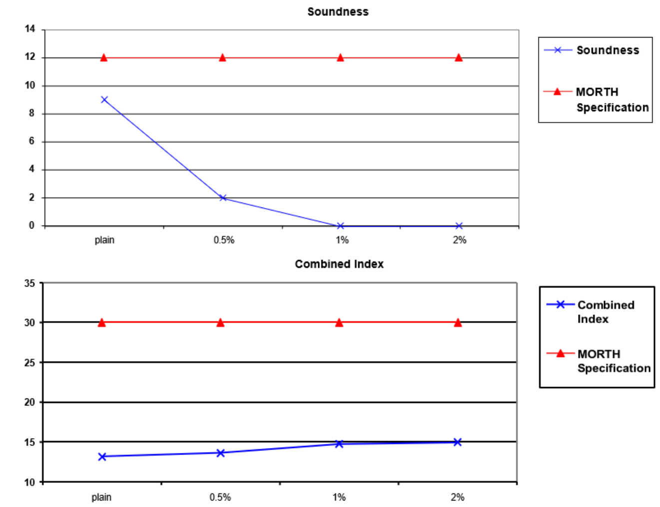


Fig -10: (a) Soundness, (b) Combined Index

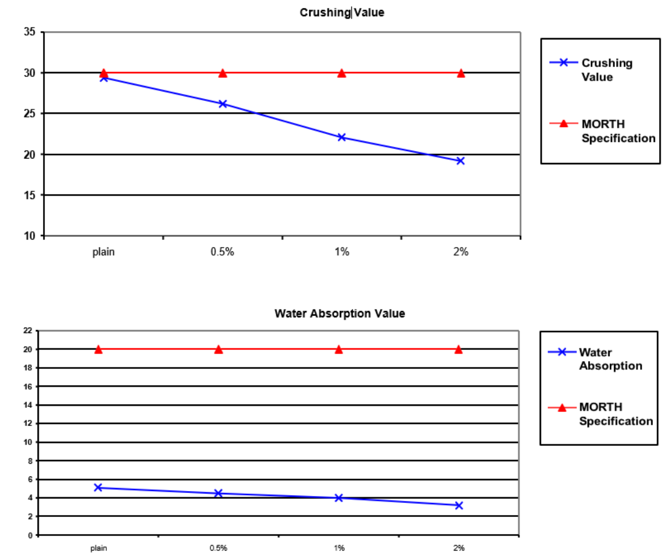


Fig -11: (a) Crushing Value, (b) Water Absorption Value

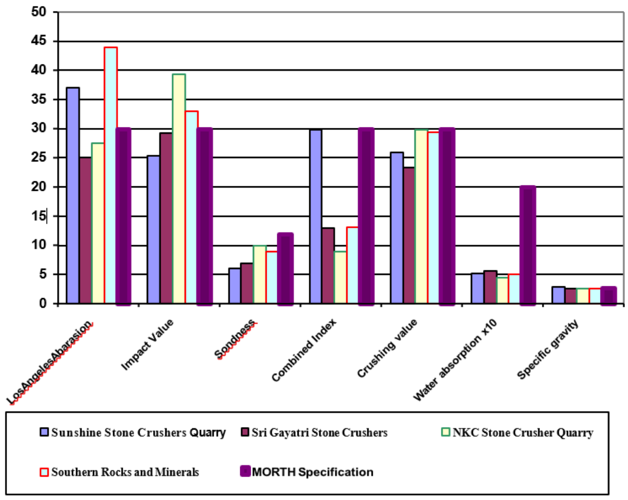


Fig -12: Physical properties of Plain aggregates of various quarries

Dry process resulted in the use of various modified materials for the construction of flexible pavements.

1. There are Polymer coated aggregate and the resulted property modification
2. Polymer coated aggregate bituminous mix, used for road construction and its related property modification.

The use of these modified materials resulted in the study of their property modification of their materials and also the related properties like

1. Binding nature of the polymers
2. Bonding nature of the bitumen at the surface of the aggregate which is coated with polymer
3. Marshall Stability Value of the mix.

This study throws more values by comparing its values of Polymer Modified Bitumen Aggregate mix.

The waste polymer which is collected from the municipal solid waste is segregated and cleaned. The cleaned polymer is shredded in to small pieces of 1.6 mm to 4.75 mm size. The aggregates are heated around 170ºC as per IRC Code, Shredded waste polymer is added to the hot aggregates and is mixed thoroughly. Polymer gets softened and forms a uniform coating over the heated aggregate. The coating takes place within 30 to 60 seconds after the polymer is added to the hot aggregate. Samples are coated with polymer by varying the percentage of polymer. In the construction of Plastic Tar Road normally a maximum of 1.50 % of the total aggregate weight is used.

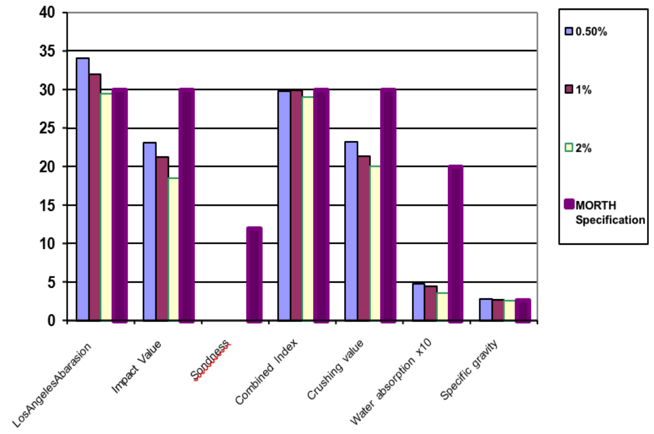


Fig -13: Laboratory test results of polymer coated aggregate of sample collected from Sunshine Stone Crushers quarry

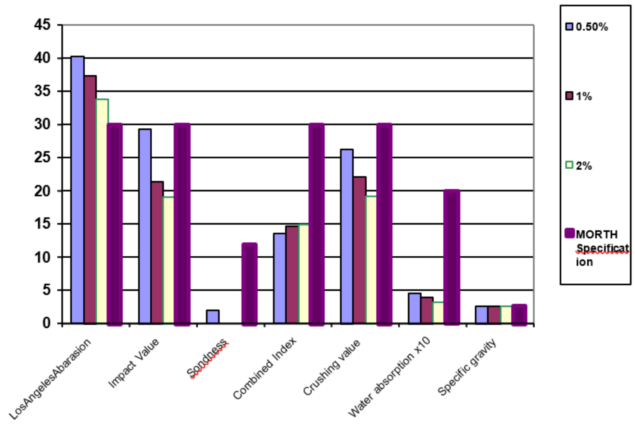


Fig -16: Laboratory test results of polymer coated aggregate of sample collected from Southern Rocks and Minerals Pvt.Ltd Quarry

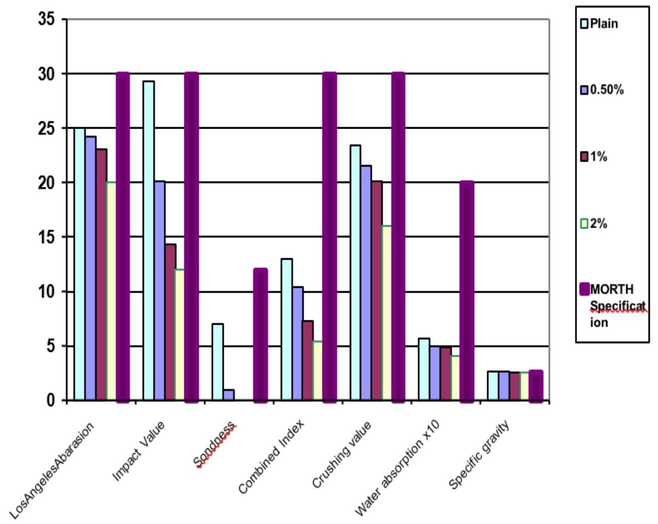


Fig -14: Laboratory test results of polymer coated aggregate of sample collected from Sunshine Stone Crushers quarry

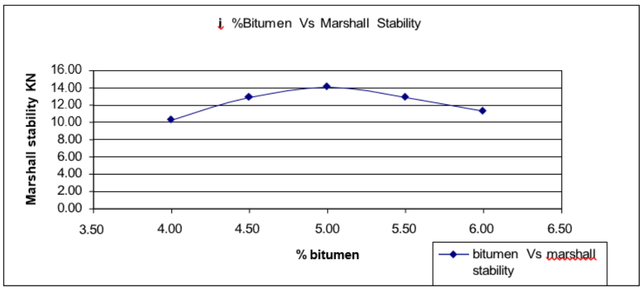


Fig -16: Percentage of Bitumen Vs Marshall Stability

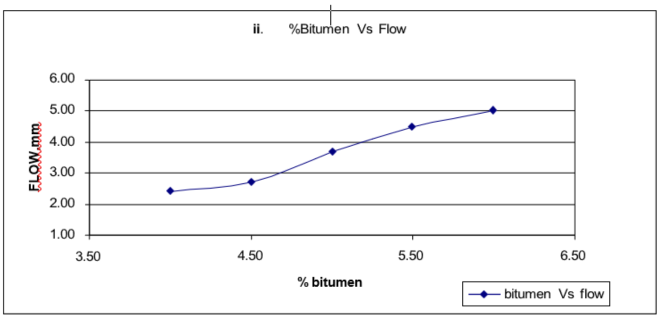
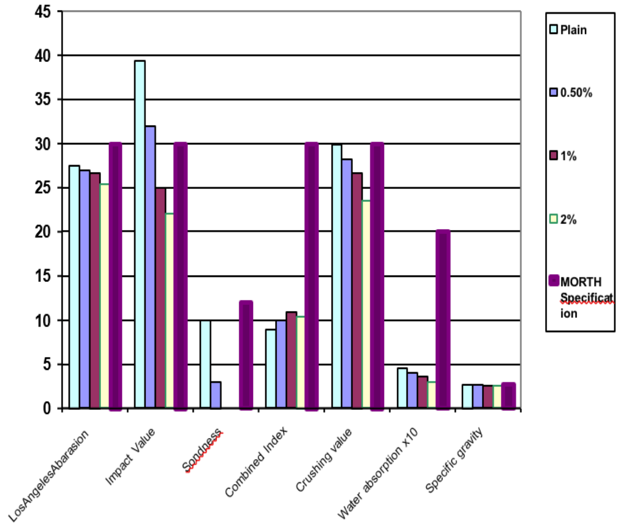


Fig -17: Percentage of Bitumen Vs Flow



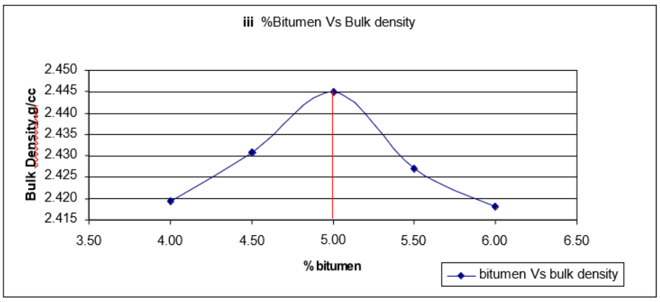


Fig -18: Percentage of Bitumen Vs Bulk Density

Fig -15: Laboratory test results of polymer coated aggregate of sample collected from NKC Stone Crusher Quarry.

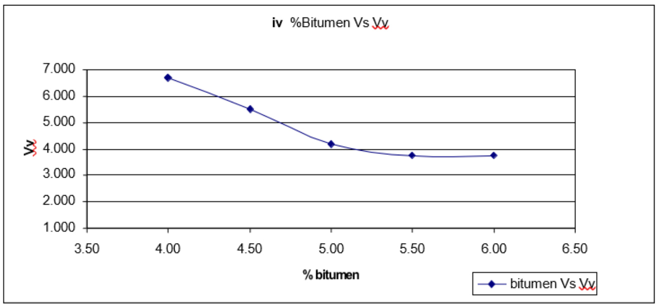


Fig -19: Percentage of Bitumen Vs Volume of voids

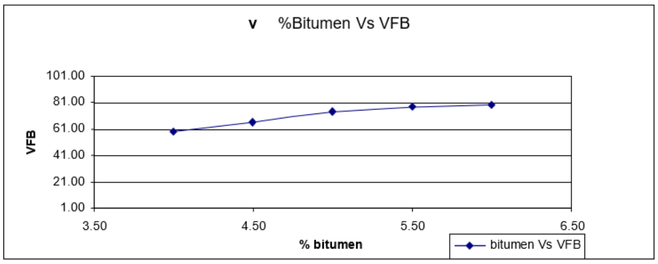


Fig -20: Percentage of Bitumen Vs Voids Filled with Bitumen

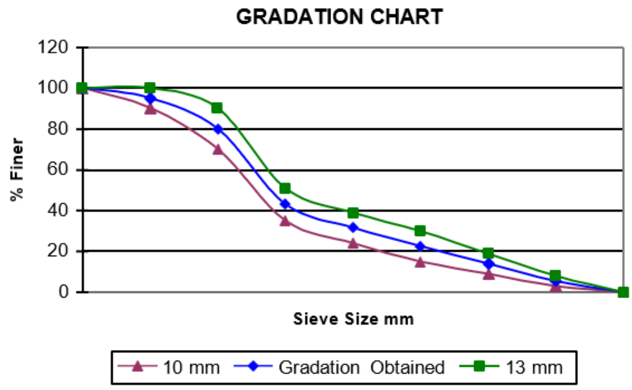


Fig -21: Gradation Graph

The below figures shows that the Marshall Stability value of Polymer Coated Aggregate is very high when compared with plain bitumen aggregate mix and polymer modified bitumen aggregate mix. This is due to the increase in the binding property of PCA mix and there is no stripping value of the PCA bituminous mix as discussed earlier for PCA.

At higher percentage, the general observation is deviated and non-uniformity in their value was observed. Ductility values show that the mix is not suitable for road construction.

The above results help to conclude that the use of higher percentage of polymer in PMB is not to be encouraged.

Whereas, in the dry process, the polymer is coated over the aggregate and bitumen is only interacting at the surface of coated polymer. This interaction is dependent on the coating thickness, type of polymer, type of bitumen etc. It is very well observed that the properties like Marshall Stability Value and stripping are showing positive results.

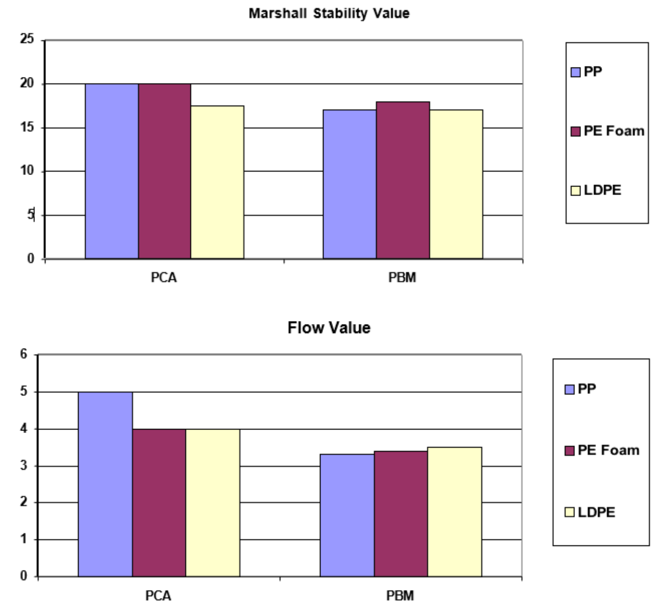


Fig -22: Comparison of Marshall Stability and Flow Value of PCA and PMB

5. CONCLUSION

- Better binding property as observed in extraction of binder test
- Higher softening point (upto53 ºC) and thereby withstanding high temperature
- Lower penetration value (65mm) and hence higher load carrying capacity
- The Marshall stability value of the Semi Dense Bituminous Concrete (SDBC)has increased by about 30 percentage on using PCA
- Water absorption was found to be less in PCA by 30.80 percentages as compared to plain aggregate which indicates a higher degree of water susceptibility.
- Comparatively better riding quality and low distress for the road sections laid using PCA mix when compared to the control section with plain aggregate mix
- The PCA mix showed better skid resistance as compared to plain aggregate mix and hence more suitable for heavy traffic
- The road using PCA was found to have a smoother surface texture as compared to those using plain aggregate.
- The unevenness of the road modified with PCA was found to be less than that of plain aggregate.
- Aggregates which are found to be not suitable for road work becomes Suitable for road works when polymer coated.
- The study shows that the physical properties of the

plain bitumen are increased by modification of EVA polymer and crumb rubber.

- Pavements made with modified bitumen are more resistant to fatigue, thermal cracking, rutting and temperature susceptibility than neat bitumen.
- As the EVA polymer and crumb rubber increases the penetration of the modified bitumen decreases.
- As the penetration value decreases, the bitumen becomes harder, due to this the quality of bitumen improves.
- The viscosity of the modified bitumen increases with the increase in EVA polymer and crumbrubber.

5.1 Scope for Further Research

1. Recycling old bituminous pavement by mixing in used polymer.
2. Boosting the strength of flexible pavement by mixing in fly ash with polymer-coated aggregate bituminous mix.
3. Use high-quality fly ash to get the desired strength.
4. Performance-based finite element modelling of flexible pavement is required.

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