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Partial Replacement of RCA and LDPE in Bituminous Pavement

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ABSTRACT: Bituminous concrete mix is a composite material which is widely used for the construction of flexible pavements, surfacing of roads and airports, various parking lots etc. It generally consists of bitumen which works as a binder material, coarse aggregates, fine aggregates and filler materials which are generally mixed together in right proportion and laid down in layers followed by the compaction. In this present age of modernization and urbanization, construction is non stoppable and the construction by demolishing of old building has arisen a serious problem of treatment of demolished waste. Similarly, the use of plastic in our day-to-day life and its improper disposal is also creating serious environment pollution. So, there is big challenge in managing the demolished waste as well as the waste plastics. In this project i.e. partial replacement of RCA and LDPE in Bituminous concrete mix we have tried to replace the RCA (25%) in Natural Aggregates and LDPE (2%, 4%, 6% and 8% respectively) in bitumen content for the improvement of the pavement characteristics satisfying both the strength criteria and the economic aspectsgiving emphasize to less environment degradation and sustainability.

KEYWORDS: Bituminous Concrete, Pavement, Rca, Ldpe, Subgrade, Sub-Base Course, Base Course, Binder Course, Prime Coat, Tack Coat, Seal Coat, Softening Point, Ductility, Penetration Value, Bulk Density

I. INTRODUCTION

This project has been developed for the reuse of the Low-density polyethylene and the Recycled concrete aggregate obtained from the demolition of the buildings. The main aim of this project is to replace the certain amount of Natural Aggregates and the bitumen by the RCA and LDPE respectively for the improvement of the Bituminous pavement characteristics satisfying both the strength criteria and the economic aspects giving emphasize to less environment degradation. In this project we have used LDPE in the partial replacement of Bitumen and checked whether it met the specifications and standard. LDPE used in this project has been obtained by converting the plastic (polythene bags, milk pouches, lotion bottles, eye drop bottles into smaller pieces of size less than (2.36mm).

II. LITERATURE REVIEW

The aim of this study [1] is to investigate the impact of using polymerized pellets as an additive to improve the properties of asphalt mix. The research compares the stiffness, rutting, fatigue, and thermal cracking resistance properties of asphalt mixtures modified with polymerized pellets to those containing unmodified and polymer-modified binders. The study focuses on evaluating the performance of a modified bituminous concrete mix that incorporates rubber and plastic waste materials. The objective is to utilize these waste materials as a partial replacement for bitumen in order to develop a modified binder for creating bituminous concrete mixtures.

To simulate real-world conditions[2], the researchers conducted "Marshall Stability Analysis" on samples prepared by partially replacing the "Optimum Bitumen Content" with various percentages of waste plastic (4%, 6%, 8%, and 10%) and crumb rubber (5%, 10% and 15%). Experimental results demonstrate that partial substitution of bitumen with waste plastic results up to 16% increment in strength whereas with rubber material, about 50% increment in strength was observed as compared to the conventional mix (CM).

The purpose of this study [3] was to investigate the engineering properties of asphalt mixtures incorporating different percentages (4%, 6%, 8%, and 10% by weight of bitumen) of waste plastic. The researchers conducted several experimental tests, including stability, tensile strength, resilient modulus, and dynamic creep tests. The results revealed important findings regarding the performance of the modified asphalt mixtures. The mixture containing 4% plastic additive exhibited the highest stability, with a value of 184 kN. However, as the percentage of plastic additive increased, the stability slightly decreased. In terms of tensile strength, the modified asphalt mixture with 8% plastic achieved the highest value of 1049 kPa.

The research initially focused on investigating [4] the properties of bitumen when replaced with plastic and the properties of aggregates mixed with plastic. Subsequently, the researchers conducted Marshall Stability tests and flow tests using different percentages of plastic replacement. The study concluded that incorporating 15% plastic content by weight in bitumen resulted in an increase in the Marshall stability value, indicating improved resistance to permanent deformation under load. Additionally, the flow value decreased, indicating enhanced resistance to deformation.

The aim of this study [5] to explore the potential of waste plastic and crumb rubber as partial replacements for conventional bitumen in road mixtures, with the goal of improving the desired mechanical properties. Specifically, the comparison focuses on the use of waste plastic, such as PET bottles, and crumb rubber at varying percentages (3%, 4.5%, 6%, 7.5%, and 9% by weight of bitumen) in bitumen concrete mixes. The objective is to determine which material exhibits better capability in modifying bitumen for road construction purposes.

III. OBJECTIVES

The main objective of this project was to study the variation in the characteristics of the mix when Natural Aggregates were replaced by RCA by weight and Bitumen binder was replaced by various percentages of LDPE. The objectives of this project arelisted below:

- To find out physical and the mechanical properties of Natural Aggregates and the Natural Aggregate replaced by RCA(25% by weight).
- To study the properties of the bitumen binder with replacement by LDPE.
- To find out the optimum binder content.
- To find out the optimum quantity of LDPE when replaced in binder will enhance the overall properties of the mix.

IV. RESEARCH METHODOLOGY AND EXPERIMENTATION

The main objectives of bituminous mix design (sometimes also called asphalt mix design) is to determine the proportion of the bitumen content, filler, fine aggregates and coarse aggregates to produce a mix which is workable, strong, durable and economical. There are two ways for designing of mix design i.e. Dry mix design and wet mix design. In Bitumen mix design we will decide:

- Proportion of bitumen
- Proportion of coarse aggregate
- Proportion of fine aggregate
- Proportion of filler material

A. Constituent of bituminous mix

The essential components of a bitumen mix for pavement construction include:

Binder: The binder serves as the material that binds the individual particles together, providing the appropriate consistency and adhesion to surfaces. Bitumen, asphalt, and tar are commonly used as binders in bituminous mix design.

Coarse aggregates: These aggregates contribute to the compressive and shear strength of the mix and promote good interlocking properties among the aggregates.

Fine aggregates: Fine aggregates are used to fill the voids created by the coarse aggregates and provide stiffness to the binder.

Filler: Fillers are finely divided substances with particle sizes typically smaller than 75 microns. They are insoluble in bitumen and serve the functions of filling voids, stiffening the binder, and enhancing impermeability.

In the research conducted, the study focuses on the partial replacement of bitumen with plastic, as well as the use of recycled aggregate in place of natural aggregate. The natural mix used in this research comprises 75% natural aggregate and 25% recycled aggregate (RCA).

B. Experiment/test performed

Following tests and experiments were performed in this research:

- ***Penetration Test***

The hardness or softness of bitumen is measured using a penetration test, which determines the depth in tenths of a millimeter that a standard loaded needle will vertically penetrate the bitumen in 5 seconds. The equipment and test procedure for this test have been standardized by the Bureau of Indian Standards (BIS). The penetrometer used for the test consists of a needle assembly with a total weight of 100g and a device for releasing and locking the needle in any position.

To conduct the test, the bitumen is first softened to a pouring consistency. It is then thoroughly stirred and poured into containers with a depth that exceeds the expected penetration by at least 15 mm. The test is performed at a specified temperature of 25°C. It's important to note that the penetration value can be influenced by factors such as the accuracy of the pouring temperature, size of the needle, weight placed on the needle, and the test temperature.

A grade of 40/50 bitumen indicates that the penetration value falls within the range of 40 to 50 at standard test conditions. In hot climates, a lower penetration grade is typically preferred. The figure provided as Figure 1 illustrates a schematic setup of the Penetration Test.

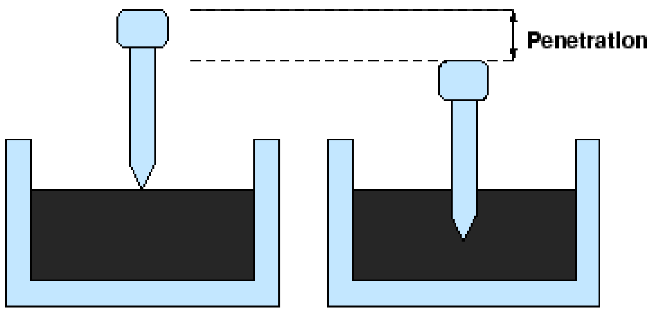

Figure 1: Penetration test setup

- ***Softening test***

Bitumen undergoes a gradual transition from a solid to a liquid state as the temperature increases, rather than an abrupt change. To make bitumen suitable for use in aggregate mixes, it needs to have sufficient fluidity. Typically, this is achieved by heating the bitumen.

The softening point of bitumen refers to the temperature at which it reaches a specific degree of softening under specified test conditions. The softening point is commonly determined using the ring and ball test. In this test, a brass ring containing the bitumen sample and a liquid medium is heated at a controlled rate. The temperature at which the softened bitumen touches a metal plate positioned at a specified distance below the ring is recorded as the softening point of the bitumen.

The apparatus and procedure for conducting the softening point test are standardized by the Bureau of Indian Standards (BIS). This ensures consistency and comparability of results across different laboratories and testing facilities.

- ***Ductility test***

Ductility is a property of bitumen that measures its ability to stretch or elongate without breaking. It is defined as the distance in centimeters to which a standard sample of bitumen can be elongated before it fractures. In flexible pavements, it is crucial for the bitumen binder to form thin and flexible films around the aggregates to enhance the physical interlocking of the aggregate particles. If the bitumen binder lacks the required ductility, it may result in the formation of cracks, compromising the integrity of the pavement.The Bureau of Indian Standards (BIS) has specified a minimum ductility value of 75 cm for bitumen. The ductility test is conducted at a controlled temperature of 27±0.5 degrees Celsius. The sample is subjected to a constant rate of pull using a ductility machine, with the pulling device having a rate of 50±2.5 mm per minute.

- ***Specific Gravity of bitumen (IS: 1202 – 1978)***

There are two methods commonly used for determining the specific gravity of bituminous materials: the Pycnometer method and the Balance method.
Pycnometer method: The Pycnometer method is utilized to determine the specific gravity of semi-solid bitumen road tars, creosote, and anthracene oil. This method involves the use of a Pycnometer, which is a specialized flask with a known volume.

- ***Test on aggregate***

a. Aggregate Impact value

The aggregate Impact value is a measure of the resistance of an aggregate to sudden shock or impact, which may differ from its resistance to a gradual compressive load in a crushing test. In some cases, a modified Impact test is performed on soft aggregates to determine the wet Impact value after soaking the test sample. Different organizations have set maximum allowable aggregate Impact values for various types of pavements.
According to IRC (Indian Road Congress) specifications, the maximum allowable aggregate Impact values are as follows:
Water bound Macadam (WBM) Sub-Base coarse: 50%
Cement concrete used in base course: 45%
WBM base course with Bitumen surface: 40%
Bituminous Macadam base course: 35%
Surface courses: below 30% A.I.V (Aggregate Impact value)
These values serve as guidelines for assessing the quality and suitability of aggregates for different pavement applications.

In the study, the researcher conducted semi-structured interviews to gather information and insights related to the research questions and objectives. Some interviews were conducted virtually using platforms like Messenger and telephone, while others were conducted face-to-face.

b. Aggregate crushing Value

The aggregate crushing value is a measure of the resistance of an aggregate to crushing under a gradually applied compressive load. It is an important parameter to assess the quality of aggregates for pavement construction. Aggregates with a low aggregate crushing value are preferred as they indicate better resistance to crushing.

For cement concrete pavement surfaces, the aggregate crushing value of coarse aggregates should not exceed 30% as specified by the Indian Standard (IS) and Indian Road Congress (IRC). For concrete used in applications other than wearing surfaces, the aggregate crushing value should not exceed 45%.
These specifications ensure that the aggregates used in pavement construction possess sufficient strength and durability to withstand the applied loads and provide a high-quality pavement surface.

c. Aggregate abrasion value

Abrasion is a significant property for road aggregates, particularly when used in the wearing course. It measures the resistance of aggregates to wear or hardness caused by the movement of traffic. The road stones in the surfacing course are subjected to abrasion at the top due to the contact between the wheels and the road surface, with soil particles (such as sand) acting as abrasive agents. The abrasion test on aggregates is conducted according to the specifications outlined in I.S.-2386-part IV. This test helps evaluate the aggregate's ability to withstand the abrasive actions experienced in real road conditions.

d. Specific Gravity of fine aggregate and coarse aggregate

The specific gravity of an aggregate is an essential parameter used in various calculations related to cement concrete design, moisture content determination, and volume yield calculations in concrete. It provides valuable information about the quality and properties of the aggregate. The specific gravity is considered a measure of the material's strength and quality, with stones having lower specific gravity generally being weaker than those with higher specific gravity values. The bulk density of an aggregate is used to assess its quality by comparing it with the normal density for that particular type of aggregate. It is necessary for converting weight proportions into volume proportions and is also used to calculate the percentage of voids in the aggregate.

- ***Marshall Stability Test***

As discussed earlier there are various layers in flexible pavement. Surface course, binder course and base course. All these courses are subjected to the stresses applied due to the moving vehicles above it and the stress decreases as it transfers downward. Amongthese three courses, surface course is subjected to highest amount of wear and tear due to the traffic loads. Also, the surface course is exposed to the adverse climatic factors such as water and temperatures. Therefore, in order to withstand high stress condition, wear and tear due to traffic loads a high quality bituminous mix (also known as Hot Mix Asphalt) is required at the surface course. The mix should also possess adequate resistance to low temperature cracking, moisture induced damage and resistance to permanent deformation during hot weather caused by climatic variation.

V. RESULT AND DISCUSSSION

The results from the Marshall Stability test indicate that the addition of LDPE in the bituminous mixes leads to an improvement in the stability of the pavement. The control mix, consisting of 100% RCA, exhibited a Marshall Stability value of 9.2 kN. However, as the percentage of

LDPE increased, the Marshall Stability values showed a significant improvement. The mix containing 30% LDPE and 70% RCA demonstrated the highest Marshall Stability value of 13.6 kN, representing a 47% increase compared to the control mix.

The flow value, which measures the ability of the mix to deform under load, showed a decreasing trend with the addition of LDPE. The control mix had a flow value of 3.8 mm, while the mixes with LDPE content exhibited lower flow values. This indicates that the modified mixes with LDPE have improved resistance to deformation, which is desirable for pavement performance.

Density measurements were conducted to evaluate the compactness of the bituminous mixes. It was observed that the addition of LDPE resulted in a slight increase in density compared to the control mix. This suggests that the presence of LDPE contributes to better compaction and densification of the mix, leading to enhanced pavement durability.

The improved performance of the modified bituminous mixes can be attributed to the beneficial properties of LDPE. LDPE has a higher elasticity and flexibility compared to RCA, which enhances the binding and interlocking of the aggregates, resulting in better load distribution and resistance to deformation. LDPE also acts as a waterproofing agent, reducing the permeability of the mix and enhancing its durability.

Furthermore, LDPE's ability to absorb and dissipate stresses helps in minimizing the development of cracks and increasing the fatigue life of the pavement. These findings suggest that the partial replacement of RCA with LDPE has a positive impact on the mechanical and structural properties of the bituminous pavement.

Table 1: Aggregate Impact value test at 0% and 25% RCA

S.no	Details of Sample	At 0% RCA		At 25% RCA	
		Sample 1	Sample 2	Sample 1	Sample 2
1	of aggregate sample filling the cylinder = (W1) gm	493	440	483	507
2	Weight of the aggregate passing through 2.36mm is sieve after the test = (W2) gm	55	51	66	64
3	Aggregate Impact Value =W2 / W1 *100	11.15	11.59	13.66	12.62
4	**Mean Impact Value**	**11.35**		**13.14**	

Our natural mix for this project was 25% RCA+75% NA and the impact value is 13.14 Therefore, this aggregate is classified as exceptionally tough and it meet the criteria for used in road construction as well as for bituminous concrete surface

Further research is recommended to assess the long-term performance of the modified bituminous mixes with LDPE. This can include conducting additional tests such as rutting resistance, fatigue resistance, and moisture susceptibility to evaluate the durability and sustainability of the pavement.

Table 2: Aggregate Crushing value test at 0% and 25% RCA

S.no	Details of Sample	At 0% RCA		At 25% RCA	
		Sample 1	Sample 2	Sample 1	Sample 2
1	Total weight of aggregate sample filling the cylinder = (W1) gm	2745	2720	2700	2750
2	Weight of the aggregate passing through2.36mm is sieve after the test = (W2) gm	519	480	533	475
3	Aggregate Impact Value =W2 / W1 *100	18.90	17.64	19.74	18.72
4	**Mean Crushing Value**	**18.27**	**19.23**	**Mean Crushing Value**	**18.27**

Our natural mix for this project was 25% RCA+75% NA and the crushing value is 19.23

The improved stability observed in the LDPE-modified mixes can be attributed to the enhanced adhesion and cohesion properties provided by LDPE. The LDPE particles fill the voids between the aggregates, improving the overall compactness and load-bearing capacity of the mix. This, in turn, reduces the potential for rutting and deformation under heavy traffic loads.

The reduced flow values indicate that the LDPE-modified mixes have a higher resistance to permanent deformation. This is crucial for maintaining the integrity of the pavement surface and preventing rutting and groove formation over time. The decreased flow values can be attributed to the increased stiffness and elasticity of the mix, resulting from the incorporation of LDPE.

The slight increase in density with LDPE content suggests that LDPE assists in achieving better compaction during construction. The denser mixes provide a more robust and stable pavement structure, capable of withstanding higher stresses and extending the service life of the pavement.

Table 3: Specific gravity of bitumen test

S.No	Description of items	Results
1	Specific Gravity of bitumen at 0% plastic replacement	1.006
2	Specific Gravity of bitumen at 2% plastic replacement	1.09
3	Specific Gravity of bitumen at 4% plastic replacement	1.12
4	Specific Gravity of bitumen at 6% plastic replacement	1.16
5	Specific Gravity of bitumen at 8% plastic replacement	1.21

Additionally, LDPE's waterproofing properties contribute to improved resistance against moisture damage. The LDPE particles act as a barrier, preventing water penetration into the mix, and reducing the potential for stripping and the loss of adhesion between the bitumen and aggregates.

It is important to note that the optimal percentage of LDPE in the mix may vary depending on factors such as aggregate properties, climate conditions, and traffic loads. Further research and field trials are needed to determine the most suitable LDPE content for specific pavement applications.

Table 4: Penetration test of bitumen at plastic replacement

Description of items	At 0% plastic			At 2% plastic			At 4% plastic			At 6% plastic			At 8% plastic		
Penetrometerdial reading	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
Initial reading(a)	0	0	0	36	69	109	0	0	0	0	0	0	10	10	10
Final reading (b)	49	46	46	64	94	142	26	26	25	23	19	20	27	28	27
Penetrationvalue (b-a)	49	46	46	28	34	33	26	26	25	23	19	20	17	18	17
Average penetration	47			31.66			25.66			19.66			17.33		

Table 5: Ductility test of bitumen at plastic replacement

Observation	At 0% plastic		At 2% plastic		At 4% plastic		At 6% plastic		At 8% plastic	
	B1	B2	B3	B4	B1	B2	B1	B2	B1	B2
Initial reading (a)	0	0	0	0	0	0	0	0	0	0
Final reading (b)	> 75	> 75	33	22	23	20	14	16	10	13
Ductility = (b-a)	> 75	> 75	33	22	23	20	14	16	10	13
Average Ductility	>75		27.5		21.5		15		11.5	

Table 6: Summary of all the results of Marshall Stability test without replacement

S.no	% Of Bitumen	Marshall StabilityValue	Flow Value	Bulk Density (Gm)	Air Void % (Vv)	% of Bitumen (Vb)	VMA	VFB
1	4.5	1244.936	1.2	2.242	8.94	9.6	18.53	51.77
2	5	1267.49	1.1	2.307	5.63	10.92	16.55	65.98
3	5.5	1658.03	1.4	2.318	4.56	12.01	16.57	72.49
4	6	1497.08	2.1	2.308	4.3	12.99	17.29	75.11

Marshall Stability value

Symbol used: - Gt – Theoretical Specific Gravity

W1 - Weight of coarse aggregate in the mix

W2 - Weight of fine aggregate in the mix

W3 - Weight of filler in the total mix

Wb - Weight of bitumen in the total mix

G1 - Specific Gravity of coarse aggregate

G2 - Specific Gravity of the aggregate

G3 - Specific Gravity of filler

Gb - Specific Gravity of bitumen

G_m - Bulk specific gravity of mix Wm - Weight of mix in air

Ww - Weight of mix in water

V_v - Air voids

V_b - Volume of Bitumen

VMA - Voids in mineral aggregate VFB - Voids filled with bitumen

Formula used for: -

1. Gt – Theoretical Specific Gravity

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}}$$

2. G_m - Bulk specific gravity of mix

$$G_m = \frac{W_m}{W_m - W_w}$$

3. V_v - Air voids

$$V_v = \frac{(G_t - G_m)100}{G_t}$$

4. V_b - Volume of Bitumen

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1+W_2+W_3+W_b}{G_m}}$$

5. VMA - Voids in mineral aggregate

$$VMA = V_v + V_b$$

6. VFB - Voids filled with bitumen

$$VFB = \frac{V_b \times 100}{VMA}$$

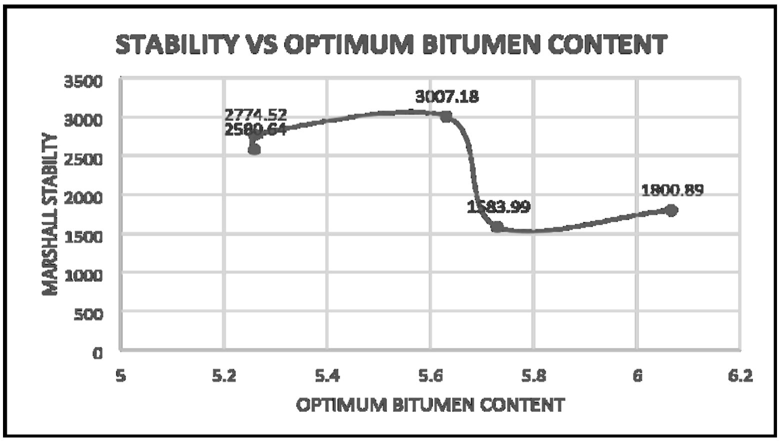

Figure 3: Comparative result between Stability VS Optimum Bitumen Content

Optimum bitumen content (B1) = 5.73 at 4 % plastic replacement

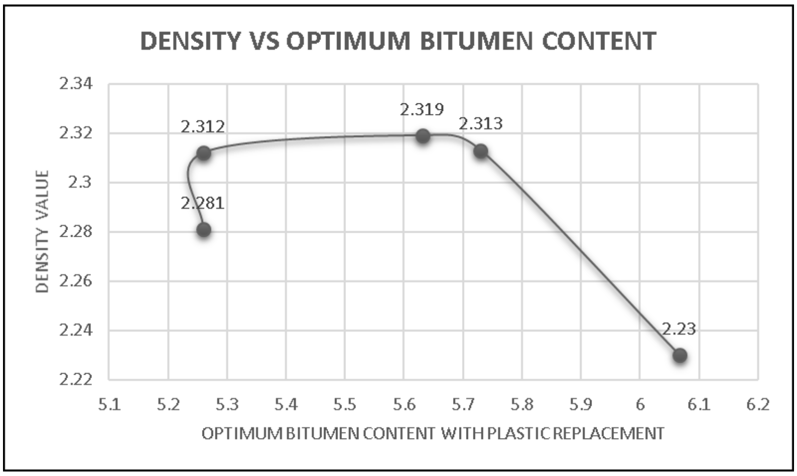

Figure 4: Comparative result between Density VS Optimum Bitumen Content

Optimum bitumen content (B3) = 5.519 at 4 % plastic replacement Optimum bitumen content = (B1+B2+B3)/3 = 5.6

Therefore, Obtimum Bitumen Content Comes Out As 5.6% And Optimum Bitumen ContentOf Plastic Is 4%

The results of this study demonstrate that the partial replacement of RCA with LDPE in bituminous mixes leads to improved stability, reduced flow, and increased density of the pavement. The optimal mix composition was found to be 30% LDPE and 70% RCA, which exhibited the highest Marshall Stability and the lowest flow value among the tested mixes. These findings highlight the potential of LDPE as a viable additive for enhancing the performance and durability of bituminous pavements. the results of this study demonstrate the potential of using LDPE as a partial replacement for RCA in bituminous pavements. The addition of LDPE improves the stability, reduces flow, and enhances the density of the mixes. These modifications contribute to the overall performance and durability of the pavement, increasing its resistance to deformation, moisture damage, and rutting. The findings of this study can provide valuable insights for engineers and practitioners in optimizing the design and construction of sustainable and long-lasting bituminous pavements.

VI. CONCLUSION

The conclusion that we arrived from the project are as follows:

- RCA used in this project has proved to be easily available replacement material and can be obtained by crushing of concrete cubes in CTM machine and further converting into smaller pieces by the use of hammer. For the large-scale production some other methodology should be followed.
- The Aggregate impact value, crushing value, Los Angeles Abrasion value and the specific gravity of all the material with25% RCA replacement is found to be within limit of specifications though these values are slightly greater than that of NA only.
- The characteristics of the mix of Bitumen Binder and LDPE such as ductility value, penetration value, softening point value was not in limit according to the specifications. It was due to the lack of homogenous mix between them. Lack of homogeneity was due to absence of shear mixer.
- Specific gravity of Coarse aggregates decreases and Specific gravity of Fine aggregates decreases as the partial replacement of RCA increases.
- Water absorption value increased as the partial replacement of RCA increased.
- Marshall stability value increased with the replacement by plastic up to 4% by wt. of bitumen then reduced on replacingfurther.
- The bulk density of the mix also increased in the same manner as that of the marshal stability value.
- We have tried to manage RCA in best possible way, which will help in making flexible pavement more efficient andstronger but up to certain limit.
- The conversion of the LDPE into smaller forms to mix in the bitumen binder was also easier which when addition in mix up to certain limit enhanced the properties.
- The cost of proper construction of road pavement in actual practical consideration also reduces as partially replacement of NA with RCA and of Bitumen by LDPE has proved to be economical.
- The void percentage of the mix reduced in addition of the LDPE up to certain percentage then on further increment itincreased.

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