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EXPERIMENTAL ANALYSIS OF PLASTIC WASTE USED IN FLEXIBLE PAVEMENT

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ABSTRACT

Rapid urbanization has resulted an exponential increase in plastic waste, which impacts the environment adversely. Plastic waste is non-biodegradable in nature that causes several health issues for a variety of species as well as mankind. To reduce the plastic waste from the surroundings and utilize it effectively in an eco-friendlier way by mixing it with bitumen for highway upgradation. It is required to conduct an assessment of existing processes for utilizing plastic waste in the enhancement of the characteristics of adaptive bitumen. Regular road products use bitumen as the base for pavements. In order to make the best layer of flexible pavement the squandered plastic chunks need to be added in the bitumen aggregate. This study examines the usability of plastic waste as an ingredient in bitumen concrete using wet method of mixing. Bitumen is modified using plastic waste of the LDPE and HDPE types. The results reveal that adding 7% of plastic waste in the bitumen mixture to increase its Marshall characteristics. In addition to making the road surface more durable, the use of plastic to replace some of the bitumen proportion is an eco-friendly method of disposing of plastic waste.

***KEYWORDS**: Waste plastic, Bituminous Concrete, Marshall stability, Aggregate, Bitumen, plastic-bitumen-aggregate mix, plastic modified bitumen.*

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INTRODUCTION

Currently, disposing of the various types of waste generated by multiple industries is a major issue. Plastic made materials are non-biodegradable which have detrimental impact on the environment [1]. It is crucial to reduce the plastic waste from the environment. In past decades, several studies had been conducted on reduction of plastic waste from the surrounding by using plastic in aggregate mix [2]. As the natural resources are depleting over time as a result of the fact that they are finite in nature and also that natural material extraction costs are rising too. As a result of this, experts are searching for new materials to use in highway construction, and one of these is waste products in the form of plastic [3]. Pollution and waste disposal issues may be mitigated to some extent if these materials are properly employed in highway construction. Traditionally, road construction involves different materials such as soil, stone aggregates, sand, bitumen, and cement, etc.

In the absence of other outlets, these solid wastes have filled many acres of land around the country. As a result, it was determined that testing and developing specifications to improve the use of these wastes in roadmaking, where larger economic returns may be achievable, was a necessary step. Low-volume roads in different sections of our country could benefit from the use of these materials [4]. It is imperative that the requisite standards be developed and that efforts be made to maximize the usage of plastic waste in various layers of the road surface. For the construction of low-volume roads, post-construction pavement performance studies have to be conducted for these waste materials:

- The land will be cleared of enormous waste dumps
- It will also help to maintain the environment by preserving the natural resources of aggregates.

Plastics are convenient for consumers, but their non-biodegradability means they must be disposed off in landfills or incinerators, both of which are environmentally unfriendly methods of disposal. Plastic is a useful substance that may also be harmful to the environment if improperly handled and disposed off. A method for properly disposing of waste plastics was made possible due to the improved binding properties of polymers in their molten condition. In hot climates, neat bitumen can produce bleeding, may develop fractures in cold climates, has a lower load-bearing capacity, and can cause catastrophic damage because of the higher axle load in existing conditions due to rapid infrastructure development [5]. While bituminous overlays used to have an average lifespan of 5–6 years, they are now said to only last approximately 3–4 years, which is far shorter than the typical lifespan of foreign pavements (5–6 years). India's transportation system must be improved in terms of both capacity and efficiency [6]. This study presents the use of trash in hot bituminous mixtures to improve pavement performance, safeguard the environment, and provide low-cost roads. By combining bitumen with various thermoplastics, shredded plastic from discarded garbage, natural plastic, or other suitable elastomers, modified bitumen (abbreviated to "modified bitumen") can be created [7].

LITERTURE REVIEW

A. V. Tiwari and Y R M Rao (2018) [10] approaches the potential of plastic waste as an ingredient for wet-mixed bituminous concrete. In the current research, bitumen is altered with the use of plastic scraps of the LDPE and HDPE varieties. The findings demonstrate that increasing the bitumen content to 6% enhances the mixture's Marshall characteristics. Plastic trash may be properly disposed of and the road surface improved by the use of plastic to cover the bitumen.

T. Choudhary (2022) [11] two waste products have been been used for the production of flexible pavement, such as “Reclaimed Asphalt Pavement Material" (RAP) and Plastic waste. For flexible pavement on Highway Design "Dense Bituminous Macadam" (DBM) Grading-II has been used. Bitumen Grade VG-30 used for binder. Adding plastic trash in accordance with IRC SP 98 2022 to hot aggregate (Dry Process) in increments of 2% up to 12% by weight of Optimum Bitumen Content (OBC). Comparative analysis revealed that RAP-25% and plastic waste-8% fulfilled all design requirements and demonstrated greater stability. By using "Reclaimed Asphalt Pavement "Material (RAP), mining and disposal issues may be avoided.

J. B Iñeguez, et. al. (2019) [12] research compares the Marshall parameters, mixture densities, and aggregates gradation derived from specimens acquired during construction to core samples retrieved 30 and 60 days afterwards. The investigation found that, with the exception of flow, all metrics assessed on core samples may be utilised to validate asphalt paving works after their installation.

MATERIALS AND METHODS

Various tests have been used to examine the effects of aggregate, bitumen, and plastic, as well as an aggregate-bitumen-plastic mix, in the current study's research technique. Tests for bitumen included the Marshall stability test, aggregate impact, and ductility [IS: 1203-1978]. The dry technique was used to combine the components of road mix. Bitumen is used in polymer-modified aggregate blends made from waste plastic and aggregates. These mixtures are then put to the test in a lab, where they yield the desired results. The mixtures of aggregates and bitumen with varied percentages of waste plastic were made separately and maintained in a water bath for at least 24 hours before being applied. The marshal stability equipment was used to assess the road pavement stability of various mixtures [8] [9].

1. Collection of waste plastic

Plastic waste is collected from a wide variety of sources, such as commercial and industrial sectors, agricultural sectors, and municipal and government sectors. Plastic wastes from industrial processes are brought together in one location before being loaded into trucks and delivered to their final destination. Large trash cans are utilised for the task of collecting waste from commercial establishments, after which the collected items are moved using vehicles. In a similar manner, waste plastic is gathered from the entire source and stored in a particular location. There are basically four different approaches that municipalities might take in order to provide recycling collection services for plastic bottles and containers. curbsides, drop-off locations, buyback initiatives, and deposit/refund programmes are all examples.

2. Cleaning of waste plastic

It is necessary to clean the plastic that has been gathered for use in the development of pavement. In the event that the plastic has impurities, these contaminants will bring about a reduction in the material's capacity to bond. The dust and dirt are combined with the plastic particles, and in doing so, they create the spaces, which are then sometimes filled with air or water. The shear capacity, hardness, and strength are all reduced due to the presence of water and air pockets. Therefore, it is necessary to clean the various fragments of plastic. But because the process of cleaning plastic can occasionally result in the chemical components of the plastic becoming mixed with the water, and because these chemicals can have a negative impact on both people and animals, this procedure does have one drawback. The cleaning procedure takes place in close proximity to water sources such as lakes and rivers. In most cases, the mills that do the cleaning are located some distance from the city. A treatment plant cleans the water that is used to wash the plastics, which drives up the cost of the process.

3. Size reducing of plastic

After the plastic has been cleaned, it is put through cutting mills, which reduce the overall size of the plastic. With the help of a shredding machine, they are reduced to sizes ranging from 2.36mm to 4.75mm. When mixed together, smaller bits produce more consistent results. The size of each piece of plastic is consistent so that its strength may be preserved. After the uncontaminated plastic has been fed into the shredding machine, the machine's output, which is in the form of shredded plastic, is then extracted. Shredding and granulating machinery are used to reduce the size of the raw polymers after they have been sorted.

These machines are able to treat a wide variety of material sizes, ranging from the typical plastic garbage generated in households to much larger lumps of waste products generated in industrial or commercial settings. All of our shredders and granulators have metal detectors installed in their purpose-built conveyor systems, as this helps us meet and maintain our stringent standards for purity and quality.

4. Clean plastic pieces

Once the plastic is cut and the pieces are reduced in size, they should be cleaned before being passed on to the next stage of the process. The plastic bits that have been thoroughly cleaned are then brought out to the field and mixed in with the aggregate. The plastic components that have been cleaned are free of any dirt, dust, clay, sand, or other contaminants.

5. Heating the aggregate and mixing with clean plastic pieces

A temperature of around 160°C is applied to the mixture. The heated aggregate is transferred into the mixing chamber after the heating process is complete. Shredded plastic garbage will be fed to the mixing chamber. Within 30 to 60 seconds, it forms an oily film on the aggregate. Because of the heat, aggregate molecules become active and firmly adhere to the clean plastic particles they come into contact with. As a result of the hot aggregate being poured on top of the clean plastic bits, they're evenly spread out. Air blast aggregate heaters are used to conduct the heating process. In the overhead bins or the receiving hoppers, hot air is used to warm the aggregate. The warm air is dispersed into the bins using pipes and diffusers by an industrial fan with high pressure.

6. Adding bitumen and Mix

The bitumen is added to the hot plastic-coated aggregate after the plastic pieces have been cleaned, reduced in size, and mixed with the hot aggregate (temperature around 165℃) (the bitumen is heated up to 160℃). Using a hot plastic-coated aggregate, the hot bitumen is mixed thoroughly. The bitumen also serves as a binder, holding together all of the aggregate.

7. Bitumen

80 / 100 grade bitumen is used in this research work and the specific gravity of Bitumen was found to be 1.011.

Table 1: Test values of bitumen mix

Sr. No.	**Test**	**Test Result**
1.	Penetration Test	90
2.	Softening Point Test	51
3.	Ductility Test	98

8. Aggregates

Fine aggregates and coarse aggregates used in this research work were seized from locally available rivers.

Table 2: Test values of Aggregates

Sr. No.	Practical values	Values as per MOST
Aggregates Impact Values (%)	20	<30
Flakiness Index values (%)	15	<25
Aggregate crushing values (%)	19	<30

- **Test on Bitumen**

1. Penetration Test (IS: 1203 – 1978)

The penetration of bitumen is described as the distance in 10th of mm that a typical needle will penetrate into the bitumen when the lord of 100 gram applied for Five seconds at 25 to 27 degrees Celsius. Penetration value of Bitumen will be greater when bitumen is softer. The penetration test is mostly used in bitumen to find the grade of material in terms of its Hardness. According to the climatic condition between distant penetration grade are adopted, therefore in hot climatic areas lower penetration values are adopted and in cold climatic areas bitumen with higher penetration values are adopted.

Bitumen is soft and to a flowing firmness between 90 degrees Celsius to 110 degrees Celsius. The sample is carefully altered to make it uniform and also free from air bubbles. The sample is then filled into the vessel of depth at least 15 mm more than the normal penetration. Temple vessels are allowed to your cold in normal temperature for one hour. Then that sample is situated in a temperature restrained water bath at a temperature of 25 to 27 degree Celsius for a one hour. Typical needle is done allowed to penetrate into the top surface of 4 4 5 seconds under a uniform loading this experiment is done with the help of instrument called as penetrometer. Code used in this test is IS: 1203 – 1978. The results of this test are given below

Table 3: Penetration value of Bitumen mix

Bitumen with Waste Plastic at different Percentages	Penetration Value, 0.01mm 100gm, 5sec, 25℃
Bitumen	94
Bitumen with 3% plastic waste	82
Bitumen with 5% plastic waste	70
Bitumen with 7.5% plastic waste	63
Bitumen with 10% plastic waste	47

2. Softening point test (IS-1205-1978)

In Softening point Test, the bituminous sample is heated at a specified temperature at which a sample attains a distinct degree of softening. The softening point of a bituminous mix is the temperature at which a disc of binder softens enough to allow a steel ball, at the beginning balls are placed on the top surface. To fall over the disc and prescribed distance is find out by ring and ball apparatus. Softening point significantly is a temperature at which binders have the same viscosity. Bitumen with high softening point is adopted in hot climatic conditions.

In this test brass rings become full with hot bitumen and allowed to cool down in atmosphere for 30 minutes. The excess vitamin is cleaned and the rings are placed at supports. The temperature of water is maintained at 5 degrees Celsius for 15 minutes. Water is increased at a gradual rate of 5 degree Celsius per minute under controlled heating apparatus, till the balls touches the bottom of the container. The softening point results are given below

Table 4: Softening Point value of Bitumen mix

Bitumen with Waste Plastic at different Percentages	**Softening point (Ring and Ball method) (℃)**
Bitumen	51
Bitumen with 3% plastic waste	58
Bitumen with 5% plastic waste	63
Bitumen with 7.0% plastic waste	68
Bitumen with 10% plastic waste	79

3. Ductility Test (IS-1208-1978)

In elastic pavement where bitumen is used as a binder. It is extensively important that there should be a ductile formation of thin film over aggregate therefore provide a suitable binder for improving the physical binding and interlocking property of aggregate bitumen mixes.

In flexible payment under a repeated action of traffic roads it shows deformation and recovery. If binding material used in flexible pavement does not show sufficient ductility value, then it cracks once a traffic load is acting on it. Therefore, ductility test of bitumen is carried out to find the property of the binder.

The value of ductility is shown as a distance in centimetres to which a standard small box of bitumen samples can be stretched until the thread breaks. The sample of bitumen is first heated and then poured in the moulds placed on the plate. The sample of bitumen along with mould are cold and then take care in water bath at 27 ℃.

The bitumen sample with mould assembly is placed in water bath of ductility testing machine for 80 to 90 minutes. Then the side of the mould assembly is detached and clips are tied with the machine and at last pointer is fixed to zero. The distance at which thread of bitumen sample breaks in centimetre is the ductility value of bituminous sample.

Table 5: Ductility value of Bitumen mix

Bitumen with Waste Plastic at different Percentages	**Ductility value (cm)**
Bitumen	107
Bitumen with 3% plastic waste	74
Bitumen with 5% plastic waste	53
Bitumen with 7.0% plastic waste	42
Bitumen with 10% plastic waste	32

4. Marshall strength test

Marshall test is determined over the bituminous mixes prepared by using the departmental specification given by MOST guidelines for the following [12].

- Bituminous concrete (Dense Graded)
- Semi Dense Bituminous concrete.
- Bituminous Macadam.

Flow value and Marshall stability value for various blends is measured. For marshal stability test, binder content is measured using following criteria.

1. Bitumen content for maximum unit weight.
2. Bitumen content for maximum stability.
3. Air voids in bitumen at 4%

Figure. 1: Marshall Stability Apparatus

IV. EXPERIMENTS AND RESULTS

$$Gt = \left[\frac{100}{(\frac{CA}{SG})+(\frac{FA}{SG})+(\frac{Bitumen\%}{SG})}\right] \text{.........................} \textbf{(1)}$$

$$VMA = *1 - \frac{Ps \times Gmb}{G_{Sb}}+ \text{x}100 \text{ ....(2)}$$

$$VFB = *100\, \frac{VMA - AV}{VMA}+ \text{ .... (3)}$$

- **At 0% plastic content effect on Bituminous Macadam**

1. Bitumen content 3.00 %

$$Gt = \left[\frac{100}{\left(\frac{CA}{SG}\right) + \left(\frac{FA}{SG}\right) + \left(\frac{Bitumen\%}{SG}\right)}\right]$$

$$Gt = \frac{100}{\left(\frac{87}{2.72}\right)+\left(\frac{9.60}{2.62}\right)+\left(\frac{3.0}{1.011}\right)}$$

Gt = 2.58

Gb = $\frac{1197}{1197-674}$

Gb = 2.289

Vv%= $\frac{(100)(2.58-2.289)}{2.58}$ **= 11.379**

Vv%=11.379

Vb% = 3.30 x $\frac{2.289}{1.011}$ **= 6.798**

VB%=6.798

VMA%= Vv + Vb **= 18.177**

VMA%=18.177

VFB%= 100 x $\frac{6.798}{13.73}$ = **37.40**

VFB%=37.40

2. **Bitumen content 3.20%**

$$Gt = \left[\frac{100}{\left(\frac{CA}{SG}\right) + \left(\frac{FA}{SG}\right) + \left(\frac{BITUMEN\%}{SG}\right)}\right]$$

$$Gt= \frac{100}{\left(\frac{86.93}{2.72}\right)+\left(\frac{9.61}{2.62}\right)+\left(\frac{3.0}{1.011}\right)}$$

Gt = 2.57

Gb = $\frac{1196}{1196-677}$

Gb = 2.302

Vv%= $\frac{(100)(2.57-2.302)}{2.57}$ **= 10.55**

Vv%=10.550

Vb% = 3.20 x $\frac{2.30}{1.011}$ **= 7.301**

Vb%=7.301

VMA%= Vv + Vb **= 17.841**

VMA%=17.841

VFB%= 100 x $\frac{10.550}{17.841}$ = **37.40**

VFB%=37.40

3. **Bitumen content 3.4%**

$$Gt = \left[\frac{100}{\left(\frac{CA}{SG}\right) + \left(\frac{FA}{SG}\right) + \left(\frac{BITUMEN\%}{SG}\right)}\right]$$

$$Gt = \frac{100}{\left(\frac{86.84}{2.72}\right)+\left(\frac{9.64}{2.62}\right)+\left(\frac{3.40}{1.011}\right)}$$

Gt = 2.56

Gb = $\frac{1195}{1195-678}$

Gb = 2.311

Vv%= $\frac{(100)(2.56-2.311)}{2.56}$ **= 11.379**

Vv%=11.379

Vb% = 3.30 x $\frac{2.311}{1.011}$ = **9.861**

Vb%=9.861

VMA%= Vv + Vb **= 17.642**

VMA%=17.642

VFB%= 100 x $\frac{9.861}{17.642}$ = **44.104**

VFB%= 44.104

Table 6: Result of Marshall Stability Test of Bituminous Macadam

Sr No.	Bitumen	Gt	Waste Plastic	Vv% Air Voids	Gb Bulk Density	VMA%	Vb%	VFB %
1	3	2.588	0	11.553	2.289	18.345	6.792	37.02469
2	3.2	2.576	0	10.54	2.304	17.833	7.293	40.8947
3	3.4	2.564	0	9.861	2.311	17.633	7.772	44.07616
4	3	2.587	3	10.531	2.359	17.531	7.000	39.92927
5	3.2	2.547	3	9.865	2.365	17.351	7.486	43.14337
6	3.4	2.539	3	9.543	2.369	17.510	7.967	45.4996
7	3	2.435	5	10.457	2.405	17.593	7.136	40.56327
8	3.2	2.411	5	9.546	2.439	17.266	7.720	44.71177
9	3.4	2.395	5	8.156	2.569	16.796	8.640	51.43956
10	3	2.465	7	8.254	2.594	15.951	7.697	48.2551
11	3.2	2.405	7	7.562	2.605	15.807	8.245	52.16135
12	3.4	2.315	7	7.214	2.646	16.113	8.899	55.22735
13	3	2.564	10	0.564	2.69	8.546	7.982	93.40057
14	3.2	2.542	10	0.56	2.765	9.312	8.752	93.98608
15	3.4	2.811	10	0.551	2.795	9.951	9.400	94.46265

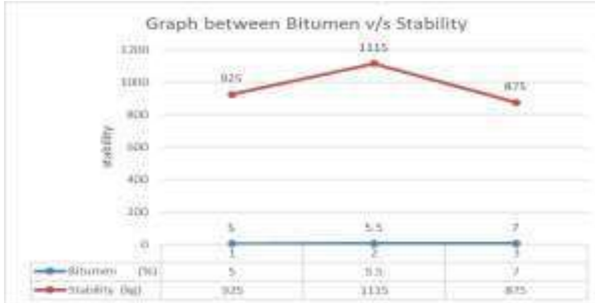

Figure. 2: Bitumen v/s Stability

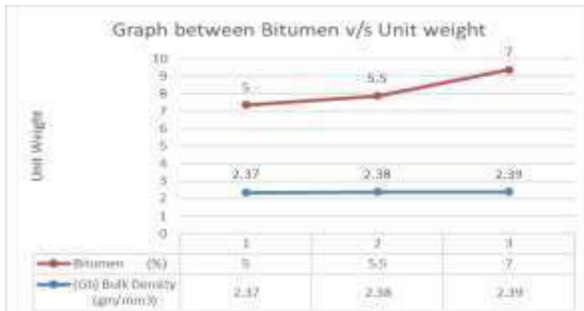

Figure. 3: Bitumen v/s unit weight

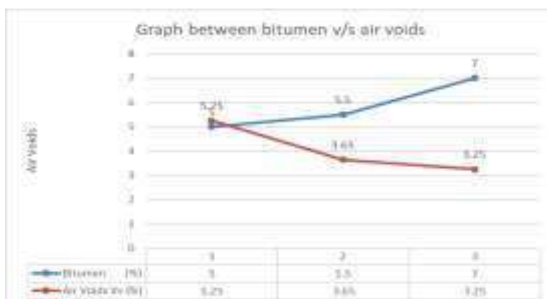

Figure. 4: Bitumen v/s Air Voids

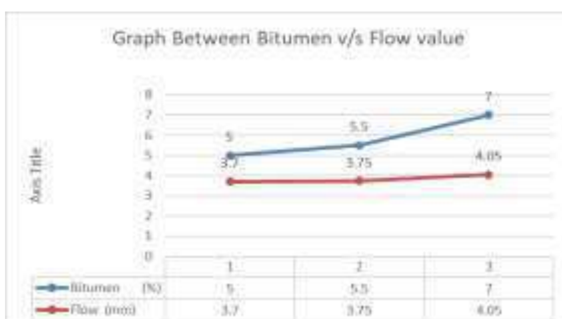

Figure. 5: Bitumen v/s flow value

- **Optimum values of Bitumen mix with Plastic Waste**

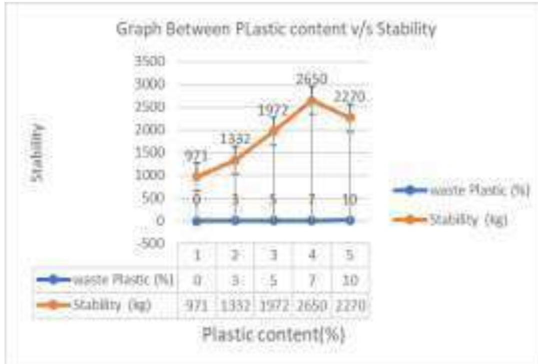

Figure. 6: Bitumen v/s Stability (S.D.B.C)

Figure. 7: Bitumen v/s Stability (B.C)

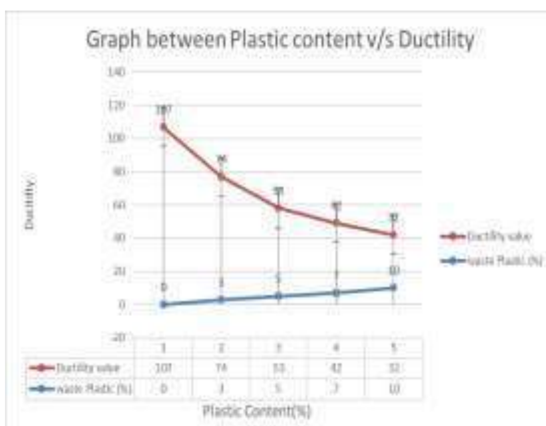

Figure. 8: Bitumen v/s Ductility

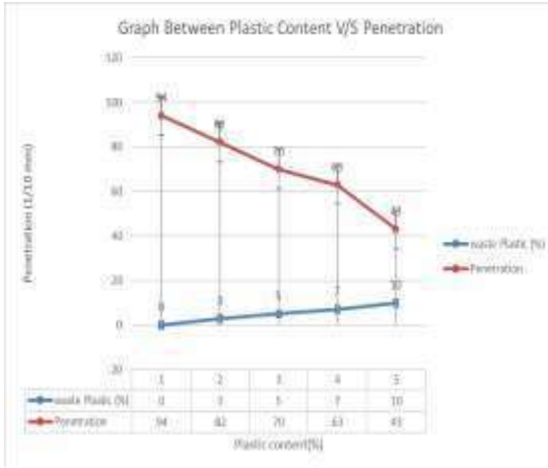

Figure. 9: Bitumen v/s Penetration

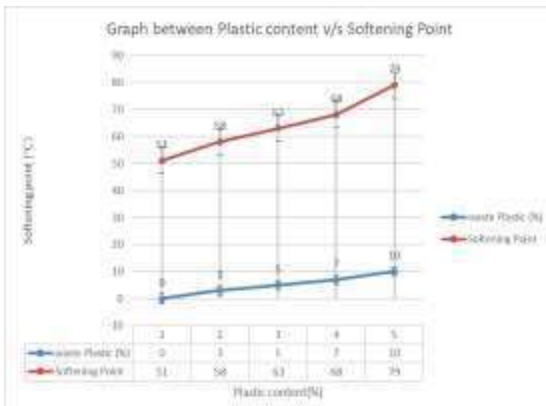

Figure. 10: Bitumen v/s Ductility

I. CONCLUSION

Utilizing plastic waste in road building also has several environmental benefits. Utilizing these waste products may minimize the roadway project's building expenses.

1) Penetration

According to experiments, increasing the quantity of plastic waste in the bituminous mix decreases the sample's penetration. When no plastic waste is used in bitumen, the penetration value is 94, but it drops to 47% when 10% is added. Therefore, adding plastic waste to bitumen increases its hardness.

2) Softening point

The Ring and Ball device measures the softening point of bitumen. The softening point is 50°C when no plastic waste is used and 79°C when 10% is added. The softening point pressure relies on the plastic waste in the sample.

3) Ductility

The ductility of bitumen is the distance in cm that a standard bitumen sample can be stretched before the thread breaks. To test bitumen's properties, its ductility is tested. The ductility of bitumen drops from 107 to 32 cm when plastic waste is added from 0 to 10% by weight of bitumen. Loss of ductility may be caused by material interlocking.

4) Stripping

Bitumen samples were found to have a stripping value of 10% after 24 hours when no plastic waste was added to the samples. After 24 hours, there was no indication of stripping when plastic waste was added to a hot bitumen sample during mixing. Bitumen mix samples were still unstriped after 72 hours.

5) Marshall Stability

The Marshall stability test is used to determine the bituminous mix's structural strength. A more stable bituminous blend means a more durable surface. Bituminous macadam, semi-dense bituminous concrete, and bituminous concrete with bitumen contents of 3.0–3.4% by weight of the total mix for bitumen mix, 5%–7% by weight of the total mix for semi-dense bituminous concrete, and 5-7 by weight of the total mix of bituminous concrete were prepared as Marshall specimens for determining Marshall stability and other parameters. The percentage of plastic trash in the bituminous mixture might range from 0-10% by bitumen weight. Before being judged, a sample of bitumen was cured in water at 60 degrees Celsius for 30 minutes.

From Test results,
In case of bituminous macadam, the samples collapsed when the Marshall specimens were taken out from water after 30 min. So, the testing of the samples couldn't be performed.

a) In the case of Semi Dense Bituminous Concrete

Marshall stability increases from 971kg to 2650kg when the plastic content increases from 0 to 10% by weight of the bitumen sample. The stability of bitumen samples is found to be maximum at 7% plastic waste content, and after that it decreases up to 2270 kg. The increases in stability are due to the improvements in the physical properties of the bituminous sample and coating of the aggregates with plastic waste. The flow value of bitumen samples also decreases up to 7% plastic content and after that it starts increasing.

b) In case of Bituminous Concrete

The Marshall stability of the bituminous mix increases from 1052 kg to 2882 kg when 0-10 % of plastic content by weight is used and afterwards it starts decreasing. The maximum stability of the bituminous mix is achieved at 7% plastic waste. The flow value decreases up to 7% plastic content and after that it starts increasing.

II. FUTURE SCOPE

The use of plastic in the construction of roads is a revolutionary technology that will not only make the road more durable but will also extend the road's useful life.

Plastic roads seem to be a highly novel way that is also ensuring better disposal. This is a necessity of the time given the rise in the amount of waste plastic produced, and it is imperative that it be used properly. Using this technology, it is possible to get rid of plastic waste in an efficient and cost-effective way. In this experiment, 7% plastic waste was used with bitumen according to the material available in the locality and also the quality of plastic. But in the future, the percentage of plastic waste should increase to 12–15%.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest

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