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STUDY OF PLASTIC WASTE BITUMINOUS CONCRETE USING DRY PROCESS OF MIXING FOR ROAD CONSTRUCTION

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Abstract:
Waste plastic is accumulated all over the world causing serious environmental problems. This paper aims to study the plastic waste bituminous concrete using dry process of mixing for road construction. The study evaluates the addition of shredded waste plastic in the bituminous concrete which results in significant increase in the stability value and Marshall Properties of mix. The study reveals that the use of waste plastic in bituminous concrete is safe and sustainable for road construction.

Key words:
Plastic Waste, Waste reuse, Road construction, Asphalt concrete

INTRODUCTION

Road network of any country is backbone of its economy. Construction of road involves huge amount of money. One can achieve the desired durability and considerable saving during the construction of roads if proper engineering design is done. The desired properties to be considered during design of bituminous mix are stability, durability, flexibility, skid resistance, workability, air voids and economy. Increase in population, rapid urbanization, development activities and change in life style has resulted in increase of quantum of plastic waste in India. This huge amount of plastic waste generated had become a serious thread to our environment. The disposal of plastic wastes is a great problem. The plastic product which is non-biodegradable result in environmental pollution and problems like breast cancer, reproductive problems in humans and animals, genital abnormalities and even in human sperm count and quality [1]. One of the solutions to this problem is to convert the waste plastic into some useful product. Indian government has already taken an initiative to implement 4R policy i.e reuse, reduce, recycle and recover through “Clean India Initiative Program”.

The generation of waste plastic has caused many effects on the environment, resulting in huge landfill which is harmful to the human health as well as to all living organisms. Therefore, the recycling and reusing of plastic wastes is found to be more advantageous. The natural bitumen extraction has resulted in more consumption of non-renewable sources which is inappropriate for sustainable development. The plastic usage in roads can replace some percentage of natural bitumen that is extracted or distilled from petroleum sources. The rutting, cracking, formation of potholes and disintegration of surface layers of flexible pavements roads due to temperature and seasonal variations, stresses due to heavy traffic loads usually occurs. Modified Bitumen is one of the important construction materials for flexible pavements which may have improved properties thereby reducing the distress faced by a conventional flexible pavement [2].

In this paper, investigation conducted for the use of plastic waste using dry process of mixing in bituminous concrete for road construction is disscussed. The objectives of the investigation are:

- To study the marshal properties of bituminous mix using plastic waste as partial replacement of bitumen and fly ash as filler.
- To find the utility of waste plastic material in bitumen mixes for road construction.
- To study and propose durable pavement surface by exploring the utilization of plastic waste and fly ash which are available abundantly.
- To provide a material for eco-friendly road way.

1 LITERATURE REVIEW

Amol S. Bhale (2011) stated that in recent years, applications of plastic wastes have been considered in road construction with great interest in many developing countries. It was concluded that on heating at 100-160°C, plastics such as polyethylene, polypropylene and polystyrene, soften and exhibit good binding properties. Blending of the softened plastic with bitumen results in a mix that is amenable for road laying. In the future, this will also result in having strong, durable and eco-friendly roads which will relieve the earth from accumulation of all types of plastic-waste [1].

R.Sathishkumar et.al, (2013) investigated and revealed that properties of bitumen can be improved with the incorporation of modifiers. The bitumen treated with these modifiers is called as “Modified Bitumen”. In their study, bitumen of grade VG 30 is selected and its properties improved by the addition of modifiers such as Low Density Poly Ethylene (LDPE) waste and Pulverised Tyre Waste (PTW). Results showed that penetration value of modified bitumen was decreases by 6.8% for PTW and 13.6% for LDPE waste. Softening point value increased by 8.16% for PTW and 14.28% for LDPE waste. Ductility value has decreased by 39.6% for PTW and increased by 18.86% for LDPE waste. In Marshall test, the stability value has increased by 30% for PTW and 28.46% for LDPE waste. Addition of the modifier reduced the flow value by 34.69% for PTW and 39.59% for LDPE waste, which induction that the flow property has increased. Thus results of this study concluded that addition of PTW and LDPE waste has improved the penetration, ductility and softening temperature of the modified bitumen. They also reported that the stiffness of the material is improved, it is capable of taking high load and increase the resistance and durability of the pavements [2].

Afroz Sultana et.al, (2012) studied utilization of waste plastic as a strength modifier in flexible and rigid pavements. The study investigates the potential use of waste plastic as a modifier for asphalt concrete and cement concrete pavement. Plastic waste in the form of carry bags, cups etc were shredded and mixed with heated aggregate to form plastic coated aggregates and this coated aggregate can be used for road construction. Investigators used different ratios of plastic such as Polypropylene (PP), Low Density Polyethylene (LDPE), and High Density Polyethylene (HDPE) by weight of asphalt. Using plastic as a coating over aggregates helps to improve the properties of aggregates. Based on the stability values, the optimum percentage of plastic is 8%, 6% for plastic coated aggregate samples and polymer modified bitumen samples respectively for PP type of plastic, and 8% is optimum for LDPE type of plastic for both plastic coated aggregate and polymer modified samples. This shows weak aggregates can be used in construction. By adding plastic to the coat aggregate, the rheological properties of the mix have improved. There is an increase in the softening point and decrease in penetration and ductility values [3].

Akanksha Yadav (2016), has reported that the use of polymer coated aggregate is better than the use of polymer modified bitumen in many aspects. The aggregate was heated at temperature about 160^oC. After the heating of aggregate, the hot aggregate is transfer into the mixing chamber. At the mixing chamber, the shredded plastics waste is to be added. It gets coated uniformly over the aggregate within 30 to 60 seconds, giving an oily look. The bitumen is added into the hot plastic coated aggregate at 160^oC. It is observed that Marshall Stability value increases with polyethylene content up to 6% and thereafter decreases and also the Marshall Flow value decreases upon addition of polythene i.e the resistance to deformation under heavy wheel loads increases [4].

Vatsal Patel et.al, (2014) highlighted the urgent need for re-examining and formulating new guidelines and specifications with regard to the design and construction of roads in India using plastic wastes. The cost of road construction is also decreased and the maintenance cost is almost nil. The roads are found to be stronger with increased Marshall Stability value. It has better resistance towards rain water and water stagnation so no stripping and no potholes. Also there is significant increase in binding property and better bonding of the mix thus reducing the pores in aggregate and hence less rutting raveling [5].

2 MATERIALS AND MIX DESIGN

Various materials used in the present study are bitumen, aggregate (fine and coarse), filler, and shredded plastic waste. The bitumen used for present study is of 60/70 penetration grade and is obtained from BPCL, Nagpur and PWD, Amravati. Coarse aggregates, fine aggregates and fly ash were collected from local producer of crushed aggregates. The plastic waste was segregated from the municipal waste and shredded at the local plastic waste recycling plant at MIDC, Amravati, India. Table 1 and Table 2 shows the physical properties of the aggregates and bitumen respectively.

Table 1: *Physical Properties of Coarse Aggregates*

Sr.no	Parameter	No. of tests Performed	Test Result	Specification Requirement	Standard
1	Impact value	3	22.40%	Max 30%	IS : 2386 (Part IV) - 1963
2	Abrasion value	3	28.10%	Max 40%	IS : 2386 (Part IV) – 1963
3	Crushing value	3	24.30%	Max 30%	IS : 2386 (Part IV) – 1963
4	Combined Elongation index and Flakiness index	3	17.20%	Max 30%	IS : 2386 (Part I) – 1963
5	Specific gravity	6	20 mm: 2.830 kg/m^3 10 mm: 2.792 kg/m^3	-	IS : 2386 (Part IV) – 1963
6	Water Absorption	3	0.1%	Max 2%	IS: 2386 (Part III)-1963

Table 2: *Physical Properties of Bitumen*

Sr.no	Parameter	Test Result	Specification Requirement	Standard
1	Penetration	68	65-90	IS : 1203-1978
2	Softening point	53ºC	40-60 ºC	IS : 1205-1978
3	Specific Gravity	1.01 kg/m^3	Min 0.99 kg/m^3	IS : 1202:1978
4	Ductility	87 mm	Min 75 mm	IS : 1208-1978

The experiment was conducted into two phases. The first phase consists of calculating the optimum value of the bitumen and second phase consists of optimizing the quantity of plastic waste used to replace the bitumen. Dry process was used to prepare Marshall Samples. In this process the coarse aggregates and fine aggregate and fly ash were heated to 170°C. The shredded plastic waste retaining on 2.36 mm sieve is added in proportion by weight to the hot aggregate. The waste plastic LDPE, PVC and HDPE was added varying from 0%, 2%, 4%, 6%, 8%, 10% and 12% by the weight of bitumen. This plastic gets coated over the aggregate uniformly. Immediately the hot Bitumen at 160°C is added to the mixture. After proper mixing the mix was placed in the compaction mould and compacted with 75 blows on both face to get Marshall Samples. The stability and flow were obtained by testing the sample on the digital Marshall frame and the average values for Bulk specific Gravity, AV, VMA and VFB were calculated and graphs were plotted. The values obtained stability values are corrected after applying the correction for thickness of the sample. According to Das, A. and Chakroborty P. the following properties were calculated based on volumetric analysis [6].

2.1 Bulk Specific Gravity of sample (Gb)

The bulk density of the sample is determined by weighing the sample (Wa) and by taking its submerged weight (Ww). The specific gravity of the specimen is given by

$$\text{Gb} = \frac{\text{Wa}}{\text{Wa} - \text{Ww}} \tag{1}$$

where: Gb = Bulk Specific Gravity of sample
Wa = Weight of sample in air (g)
Ww = Weight of sample in water (g)

2.2 Theoretical specific gravity of the mix (Gt)

Theoretical specific gravity Gt is the specific gravity without considering air voids, and is given by:

$$\text{Gt} = \frac{\text{P1} + \text{P2} + \text{P3} + \text{Pf} + \text{Pb}}{\frac{\text{P1}}{\text{G1}} + \frac{\text{P2}}{\text{G2}} + \frac{\text{P3}}{\text{G3}} + \frac{\text{Pf}}{\text{Gf}} + \frac{\text{Pb}}{\text{Gb}}} \tag{2}$$

where: P1 is the Percentage by weight of 20mm coarse aggregate in the total mix
P2 is the Percentage by weight of 10mm coarse aggregate in the total mix
P3 is the Percentage by weight of Stone Dust in the total mix
Pf is the Percentage by weight of filler in the total mix
Pb is the Percentage by weight of bitumen in the total mix
G1 is the specific gravity of 20mm coarse aggregate
G2 is the specific gravity of 10mm coarse aggregate
G3 is the specific gravity of Stone Dust
Gf is the specific gravity of Filler
Gb is the specific gravity of bitumen

2.3 Bulk Specific Gravity of Aggregate (Gsb)

$$Gsb = \frac{P1 + P2 + P3 + Pf}{\frac{P1}{G1} + \frac{P2}{G2} + \frac{P3}{G3} + \frac{Pf}{Gf}} \quad (3)$$

where: P1 is the Percentage by weight of 20mm coarse aggregate in the total mix
P2 is the Percentage by weight of 10mm coarse aggregate in the total mix
P3 is the Percentage by weight of Stone Dust in the total mix
Pf is the Percentage by weight of filler in the total mix
G1 is the specific gravity of 20mm coarse aggregate
G2 is the specific gravity of 10mm coarse aggregate
G3 is the specific gravity of Stone Dust
Gf is the specific gravity of filler

2.4 Air voids percent (AV)

It is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture. The amount of air voids in a mixture is extremely important and closely related to stability, durability and permeability. The following equation represents the percentage of air voids in the specimen.

$$AV = \frac{(Gt - Gb)100}{Gt} \quad (4)$$

where: AV is the Percentage of Air voids
G_t is the Theoretical specific gravity of the mix
Gb is the Bulk Specific Gravity of sample

2.5 Voids in the Mineral Aggregate (VMA)

VMA is the volume of inter granular void space between the aggregate particles of a compacted paving mixture. It includes the air voids and the volume of the asphalt not absorbed into the aggregate .VMA describes the portion of space in a compacted asphalt pavement or specimen which is not occupied by the aggregate. VMA is expressed as a percentage of the total volume of the mix Voids Filled with Binder (VFB).

$$VMA = \left[1 - \frac{Ps \text{ x } Gmb}{Gsb}\right]100 \quad (5)$$

where: Ps = Aggregate content, %
Gsb = Bulk specific gravity of total aggregate
Gmb = Bulk specific gravity of mixed aggregate

2.6 Voids Filled with Bitumen (VFB)

VFB is the voids in the mineral aggregate frame work filled with bitumen binder. This represents the volume of the effective bitumen content. It can also be described as the percent of the volume of the VMA that is filled with bitumen. VFB is inversely related to air voids and hence as air voids decreases, the VFB increases.

$$\mathrm{VFB} = 100\frac{(\mathrm{VMA} - \mathrm{AV})}{\mathrm{VMA}} \tag{6}$$

where: AV is air voids in the mix and
VMA is the voids in the mineral aggregate.

3 RESULTS

The optimum binder content for the mix was found to be 6% since the maximum stability was found at 6 % of binder content. The obtained value was further used for the subsequent study. During the experiment PVC plastic waste was also used but while spreading the shredded PVC plastic on heated aggregate some gases were coming out of the mix and hence PVC plastic was not used for further experiment. The details of volumetric and mechanical properties are tabulated below in the Table 3 and figure 1,2,3,4 and 5.

Table 3: *Optimum Bitumen Value Calculation*

Bitumen content %	Bulk Specific Gravity Gb (g/cm^3)	Theoretical Specific Gravity Gt (g/cm^3)	Void Analysis			Marshall Stability (kN)		Flow (mm)
			AV (%)	VMA (%)	VFB (%)	Measured	Corrected	
5	2.195	2.389	8.131	23.046	64.818	10.52	9.40	2.32
5.5	2.204	2.361	6.673	23.146	71.334	12.14	10.69	2.54
6	**2.205**	**2.334**	**5.527**	**23.508**	**76.605**	**13.89**	**11.95**	**2.64**
6.5	2.200	2.307	4.639	24.076	80.897	12.11	10.70	3.22
7	2.198	2.281	3.638	24.552	85.285	11.56	10.05	3.72

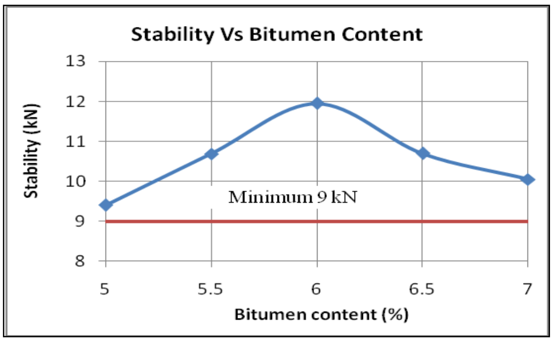

Fig.1 *Bitumen Content Vs Stability*

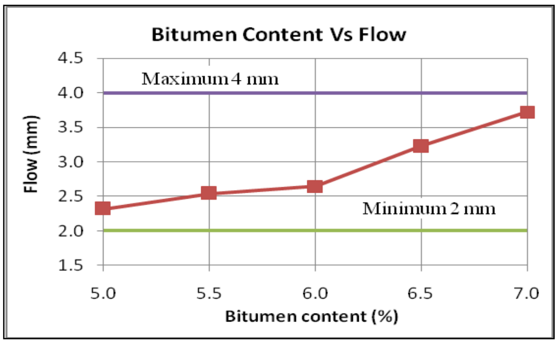

Fig.2 *Bitumen Content Vs flow*

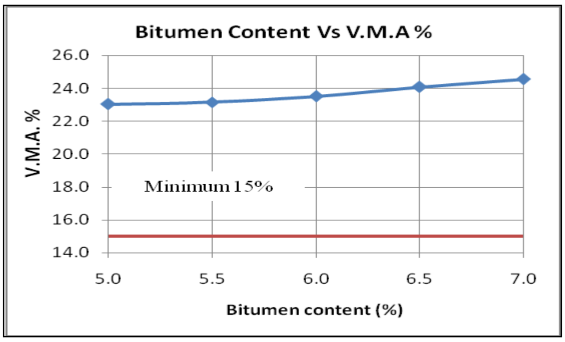

Fig.3 Stability Vs V.M.A %

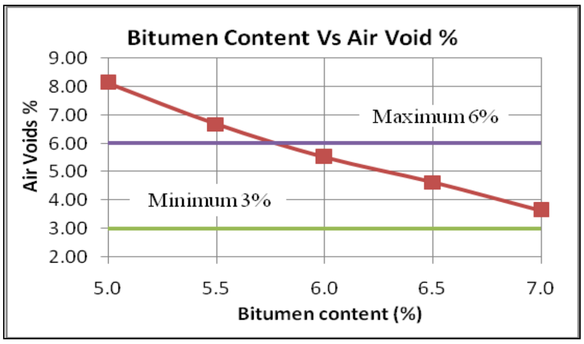

Fig.4 Bitumen Content Vs Air Void %

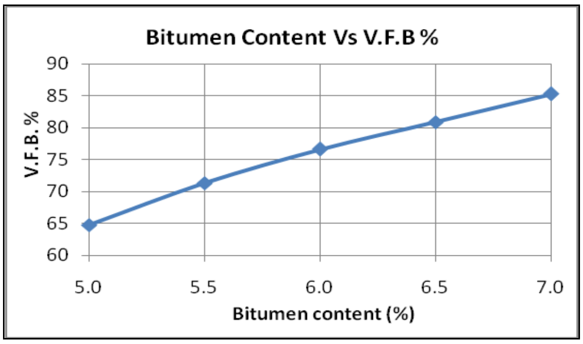

Fig.5 Bitumen Content Vs V.F.B %

The volumetric and mechanical properties of the mix were obtained after adding LDPE and HDPE plastic material at 2%, 4%, 6%, 8%, 10% and 12% by the weight of bitumen and the results are tabulated below in the Table 4 and figures 6,7,8,9 and 10.

Table 4: *Optimum value for percentage of plastic waste*

Type of Plastic	Plastic Waste %	Bulk Specific Gravity Gb (g/cm³)	Theoretical Specific Gravity Gt (g/cm³)	Void Analysis			Marshall Stability (kN)		Flow(mm)
				AV (%)	VMA (%)	VFB (%)	Measured	Corrected	
	0	2.205	2.334	5.53	23.51	76.61	13.89	11.95	2.64
LDPE	2	2.232	2.334	4.38	22.58	80.64	12.95	12.43	2.57
HDPE	2	2.236	2.334	4.20	22.44	81.49	13.17	12.81	2.71
LDPE	4	2.236	2.334	4.20	22.43	81.85	13.30	12.51	2.68
HDPE	4	2.240	2.334	4.04	22.31	82.15	13.77	12.89	2.71
LDPE	6	2.244	2.334	3.85	22.15	82.61	15.37	13.52	2.74
HDPE	6	2.253	2.334	3.48	21.85	84.08	15.25	13.57	2.87
LDPE	**8**	**2.252**	**2.334**	**3.53**	**21.89**	**83.89**	**16.52**	**14.70**	**3.30**
HDPE	**8**	**2.259**	**2.334**	**3.19**	**21.62**	**85.34**	**16.92**	**15.51**	**3.51**
LDPE	10	2.243	2.334	3.90	22.19	82.44	14.56	13.16	3.83
HDPE	10	2.247	2.334	3.72	22.04	83.15	15.01	13.90	3.92
LDPE	12	2.237	2.334	4.15	22.39	81.77	14.37	13.17	3.97
HDPE	12	2.248	2.334	3.70	22.03	83.39	15.34	14.06	4.22

The maximum stability was found to be 14.70 kN and 15.51 kN for the 8% of LDPE and HDPE plastic waste content respectively. The addition of waste plastic at 8% increased the stability value which resulted in the improvement of toughness of the mix. Subsequently, the flow value of the mix has increased which results in the increase in the workability of the mix.

The excessive air void may result in the cracking due to insufficient bitumen binders, where as low air void may produce more plastic flow and result in bitumen bleeding. The air voids for the 8% of the LDPE and HDPE plastic waste content was found to be within the specified limit of minimum 3% to maximum 6%. Also the other properties like VMA and VFB were found to be well within the limits.

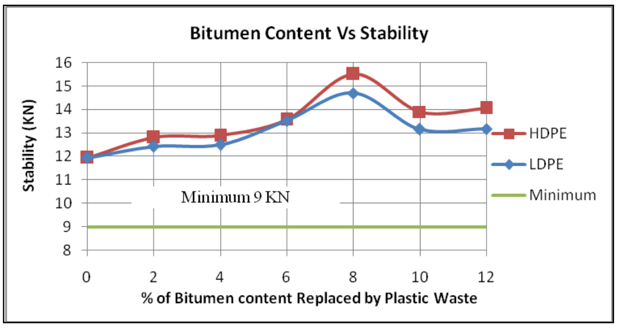

Fig.6 *% of Bitumen replaced by plastic waste Vs Stability*

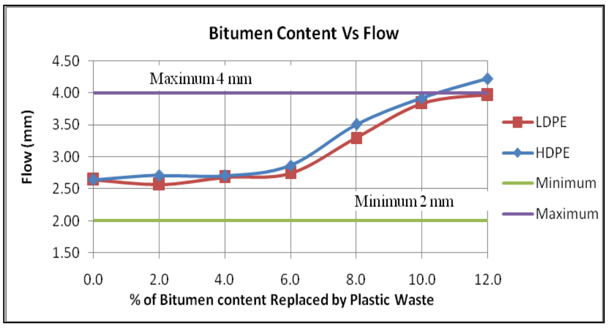

Fig.7 *% of Bitumen replaced by plastic waste Vs Flow*

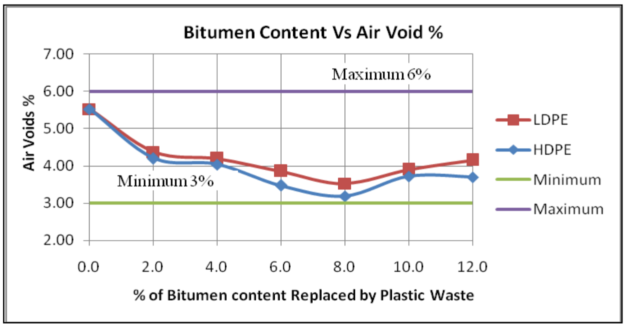

Fig.8 *% of Bitumen replaced by plastic waste Vs Air void %*

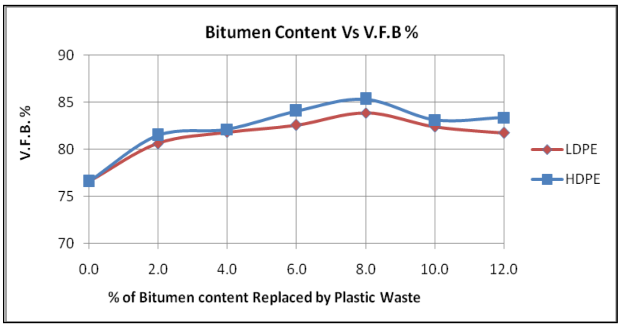

Fig.9 *% of Bitumen replaced by plastic waste Vs V.F.B %*

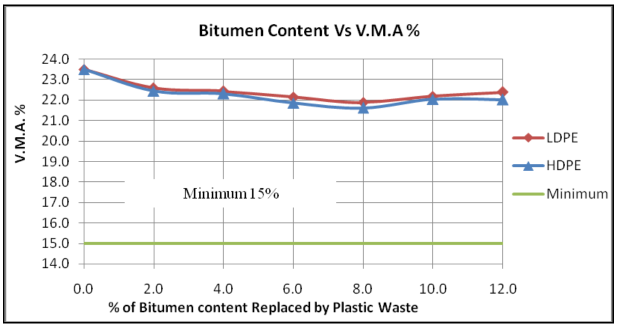

Fig.10 *% of Bitumen replaced by plastic waste Vs V.M.A%*

4 CONCLUSION

- From the study of Plastic Waste Bituminous Concrete Using Dry Process of Mixing for Road Construction it can be concluded that addition of plastic improves the Marshall properties of the mix.
- The Addition of 8% of the LDPE and HDPE plastic waste improves the stability value of the bituminous mix which results is the increase in the toughness of the mix. The roads can withstand heavy traffic and shows better service life.
- Due to addition of plastic waste the flow value increases resulting the improvement in the workability.
- Addition of plastic waste results in decrease in the air voids which reduces the bleeding of bitumen.
- The volumetric and Marshall properties of the mix show the acceptable trends and could satisfy the specified limits.
- This study has a positive impact on environment and the use of waste plastic in bituminous concrete is eco-friendly way of using waste plastic for road construction.

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