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Study on the utilization of Waste Plastic in Bituminous Concrete Mix for Road Construction

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Abstract: The mechanical properties of bituminous mix modified with two different plastic wastes of thickness more than 40 micron and less than 40 micron via dry process was examined in this study. Properties like Marshall Stability, Flow, Indirect Tensile Strength (ITS) and Retained Stability values were calculated to evaluate the suitability of waste plastics in Road construction. The results obtained showed that the waste plastic modified bituminous mixes were performed similar and better than the conventional bituminous mix. The physical properties like Abrasion value, Crushing Strength value, and Impact value and water absorption of modified aggregates via dry process were also improved. This holds out new possibilities for utilization of locally available aggregates of variable quality, for manufacturing mixture with better performance. The utilization of locally available aggregates would make the mixture economical. Waste plastics are generallydisposed by landfilling or left alone in the environment which leads environmental pollution and causes many diseases to human beings and animals. Thus, the utilization of waste plastic as modifier by replacing base bitumen can be economical and environmental friendly.

Keywords: Less than 40 micron waste plastic, more than 40 micron waste plastic, dry process, Marshall Stability, Modified Bituminous mix.

Introduction

This paper deals with the improvement in mechanical properties of bituminous mixes by using waste plastic. There are two different methods of mixing of waste plastic in bituminous mix i.e. via dry process and wet process. In dry process aggregates are modified whereas in wet process bitumen is modified (IRC:SP:98:2008). In dry process higher percentage of waste plastic can be used with respect to wet process and utilization of waste plastic is economical (Vasudevan et al. 2012). There are verities of waste plastics available to use in road construction like carry bags, Recycled concrete aggregate (RCA), Crumb Rubber, LDPE and HDPE (Malik 2014, Imran et al. 2016).

Sometimes, RCA and Crushed Brick (CB) are blend with waste plastic to use in the construction of pavement that also significantly increased the mechanical properties of mixtures (Perera et al. 2019). Generally around the Globe, PET is mostly used as a modifier for the mixture which in results enhances the service life and decreases the thickness of the base course (Abo et. al. 2019, Perera et al. 2019). LDPE is found to be most effective in resisting rutting properties at all temperature and crumb rubber shows improved properties at highest temperature of 70˚C (Imran et al. 2016). Depending upon the verity of waste plastic utilized, better resistance towards fatigue cracking has also been found (Costa et al. 2013). In wet process, as the percentage of HDPE increases there is decrement in penetration value and temperature susceptibility while there is increment in softening point of modified bitumen (Attaelmanan et al. 2011). In dry process, the physical properties of aggregates show better results than conventional aggregates (Vasudevan et al. 2012). The modified bituminous mixes show higher Marshall Stability, Flow and Indirect Tensile Strength than conventional bituminous mix (Mukesh et al. 2019).

Flexible pavement is the most widely constructed pavement in India. So, making it more effective in load carrying, service life and operation in all weathers condition is one of most important work for the Researcher and also making it economic and environmental friendly. Environmental pollution has been the biggest problem caused by the burning of waste plastic and filling the land with waste plastic (Apurva 2013). Many laboratory investigation reports show that the utilization of waste plastic in flexible pavement enhances the mechanical properties and also eco-friendly and economical (Apurva 2013).

Considering above information, one of the main objective of this study was to investigate the effects of using waste plastic in bituminous mixes and extent of improvement in mechanical properties of bituminous mixes. The main advantage of this study considering that the waste plastics are currently dispose through landfilling, incretion or left alone in the atmosphere which leads to the environmental pollution and causes diseases to human beings and animals.

Materials and Methods

In the design of bituminous mix/modified bituminous mix; it requires different kinds of materials like aggregates, bitumen, waste plastic and filler. Each and all materials have their own characteristics and properties which are described below. Marshall Mix sample is prepared according to AASHTO T 245. Sample of dimension of 101.7 mm diameter and 63.5 mm height and weight of 1200gm was prepared. Before the preparation of the sample some tests were conducted on aggregates and bitumen and after that blending were done to achieve the mixdesign of aggregate gradation.

Materials

Aggregates

The aggregates used in this study came from crushed rocks of Gaya and the filler was OPC cement. The physical characteristics of aggregates are listed in Table-1. The mechanical and volumetric characteristics of bituminous mixes depend directly on the proportioning of material used. The proportion of aggregates taken in bituminous mix (Grade-II) was calculated as per the MORT&H, 2013 requirement using analytical method, represented in Table-2 & Figure-1 to fulfil the gradation requirement.

Aggregates were modified with waste plastics by coating the aggregates with molten plastics in the dry process. Coating of aggregates was done by heating the aggregates to the melting point of respective waste plastics so that they will not release toxic gases.

For modified aggregates, the mix grading curve was kept same as that of conventional aggregates in order to highlights the effect of addition of waste plastic. The physical properties of modified aggregates are shown in Table-4.

Bitumen

The base bitumen used in this study was VG-30 grade. The physical properties of base bitumen are detailed in Table-2. The physical properties were determined as per as the specification and also checking was done to validate the results.

Table-1 Physical properties of Aggregates

Properties	As Per	Size	Result	Specification limit
Aggregate Impact value	IS: 2386	20 mm 10 mm	8.11	30
Aggregate Crushing value	IS: 2386	20 mm 10 mm	18.3	45
Aggregate Abrasion value	IS: 2386	20 mm 10 mm	23.47	30
Shape Test	IS: 2386	20 mm 10 mm	FE: 13 EE: 11	FE+EE= 30
Specific Gravity	IS: 2386	20 mm 10 mm Stone Dust	2.70 2.75 2.69	2.5-3.0 2.5-3.0 2.5-3.0

Table-2 Physical Properties of Bitumen

Properties	Results	Specification limit	As Per
Penetration Value	68	60-70	IS: 1203:1978
Softening Point	52	50-55	IS: 334-1982
Specific Gravity	1.0	1.01	IS: 1202:1978

Table-3 Gradation Curve of Aggregates

	Limit		Cumulative % weight of aggregates				Total
Sieve	**Lower**	**Upper**	**A (20 mm)**	**B (10 mm)**	**C (Stone dust)**	**D (Filler)**	
19	100	100	93.92	100	100	100	98.97
13.2	90	100	44.92	100	100	100	90.64
9.5	70	88	0.68	76.8	100	100	77.31
4.5	53	71	0.28	5.0	98.2	100	58.31
2.36	42	58	0.26	0.15	86.3	100	50.55
1.18	34	48	0.20	0.10	60	100	36.06
0.6	26	38	0.20	0.10	50.7	100	30.94
0.3	18	28	0.20	0.10	28	97.20	18.38
0.15	12	20	0.20	0.10	20	94.40	13.89
0.05	4	10	0.20	0.10	5.3	60.20	4.78
Material used (%)			17	25	55	3	100

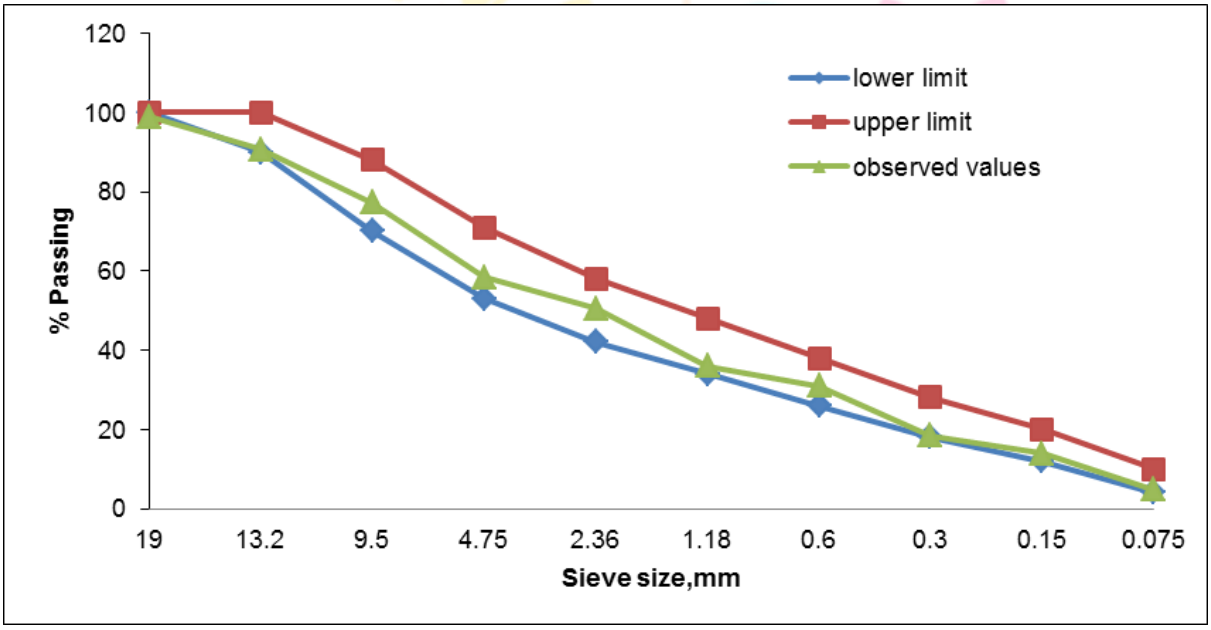


Figure-1 Gradation Curve

Waste Plastic

The waste plastics used in this study as a modifier, Milk Pouch (LDPE) and Biscuit Cover (PP) collected from the market and shredded in the size range of 0.125 mm and 4 mm. The density of LDPE and PP is 0.94 g/cm^2 and 0.91 g/cm^2 respectively. These densities were calculated according to ASTM D792.

(a) (b)

Figure-2 Sample of (a) Milk Pouch and (b) Biscuit Cover used in this study

Table-4 Properties of Modified Aggregates

Properties	Modified Value		% Improvement	
	LDPE	PP	LDPE	PP
Aggregate Impact value	6.89	7.12	15.04	12.21
Aggregate Crushing value	14.64	15.83	20	13.50
Los Angeles Abrasion value	18.07	20.65	23	12.02
Water Absorption	NIL	-	-	-

Methods

Mix Design

Sample was prepared by heating aggregates at 150˚C-165˚C temperature and asphalt was heated at 135˚C temperature so that both the pavement materials will mix properly and thoroughly. After mixing the mix was brought in the mould keeping temperature not less than 145˚C and the mould had been compacted with the help of a hammer. The mould would be given 75 numbers of blows on either side and then sample is left at room temperature for 24 hours.

Marshall Method of mix design is the globally adopted procedure for mix design of high-grade bituminous mixes such as DBM and BC. Optimum bitumen content is obtained through Marshall Method of mix design by calculating properties of bituminous mix like stability, flow, percentage air void and density. Bitumen content which satisfies all the criteria as mentioned in MORT&H, 2013 is termed as optimum bitumen content. In the present study optimum bitumen content was evaluated for bituminous concrete of G-II grading and it was 5.50.

(a) (b)

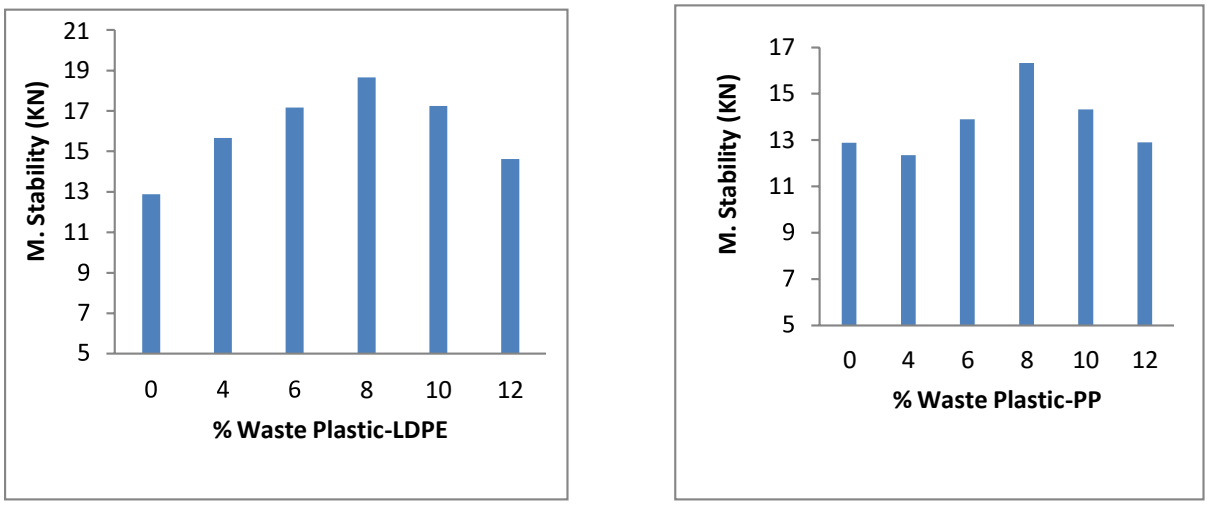
Figure-2 Specimen of (a) Conventional Bituminous Mix and (b) Modified Bituminous Mix

Marshall Moulds were prepared by utilizing waste plastics as a modifier via dry process. The modifier used were Milk Pouch (LDPE) and Biscuit Cover (PP) in the range of 4%, 6%, 8%, 10% and 12% of weight of optimum bitumen content and various mechanical properties like Marshall Stability, Flow, Marshall Quotient, Retained Stability and Indirect Tensile Strength (ITS) were evaluated as well as compared with IRC: 98-2013 specification for validation of utilization of waste plastics as a modifier.

Results and Discussion

Marshall Stability

The Figure-3 shows the Marshall Stability values of the modified bituminous mix (waste plastic-LDPE (Milk Pouch)) and modified bituminous mix (waste plastic-PP (Biscuit Cover)) at different percentage of waste plastic content respectively. Marshall Stability value of the modified Marshall Mixes are more than the conventional Marshall mix because the bond formed between the plastic and bitumen is much stronger than the bond formed between aggregates and bitumen in the conventional bituminous mix. Marshall Stability value for waste plastic-LDPE is higher than that of waste plastic-PP because the bond between plastic and bitumen for waste plastic-LDPE is stronger than the bond between plastic and bitumen in the case of waste plastic-PP. It is also observed that with the addition of higher percentage of waste, stability value decreases because of the weak adhesion of the mixes due to availability of lesser amount of bitumen as higher percentage of bitumen is replaced by waste plastic. The highest Marshall Stability is observed at 8% waste plastic content for both types of waste plastics.

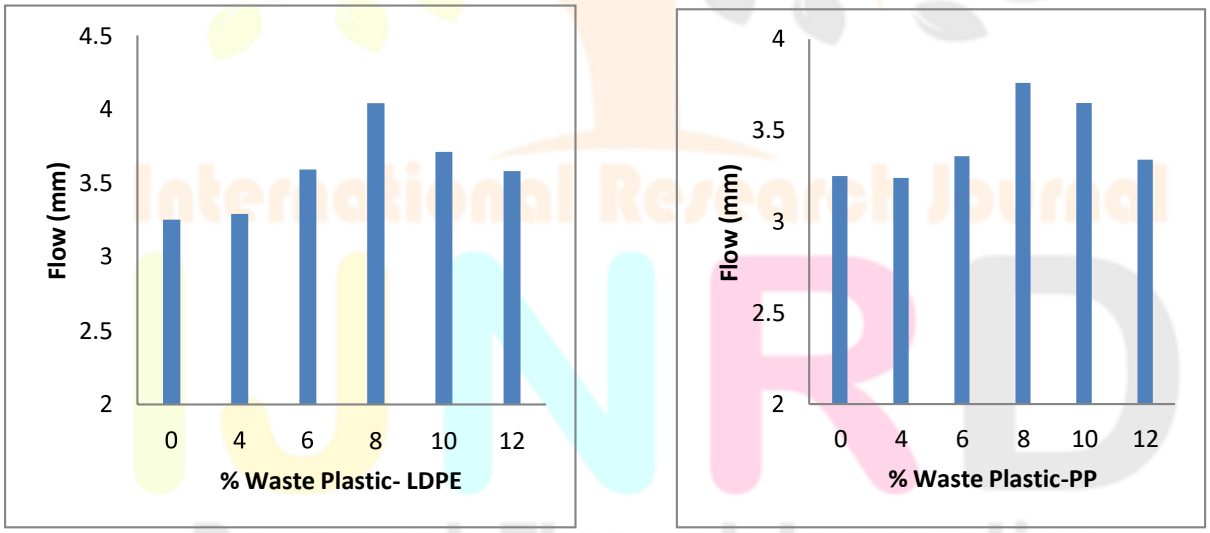


(a) (b)

Figure-3 Marshall Stability value at different % Waste Plastic (a) LDPE and (b) PP

Flow value

The Figure-4 shows the variation of Flow values of the modified bituminous mixes for waste plastic-LDPE and waste plastic-PP at different percentages of waste plastic (% by weight of optimum bitumen content). Initially, flow value increased with increment in % waste plastic amount to the optimum value then decreased. Flow value of the waste plastic coated bituminous mixes was more than the conventional bituminous mixes becauseof enhancement in the elastic behavior of mixes which showed that the modified bituminous mixes could displace more before breaking/failure. At the optimum bitumen content, flow was 3.26 and at the plastic content of 8%, flow was 4.04 and 3.76 for waste plastic-LDPE and waste plastic-PP respectively. It was also observed that with the increase in percentage plastic content, flow value decreases due to increase in stiffness property of bituminous mixes at higher percentage of waste plastics.

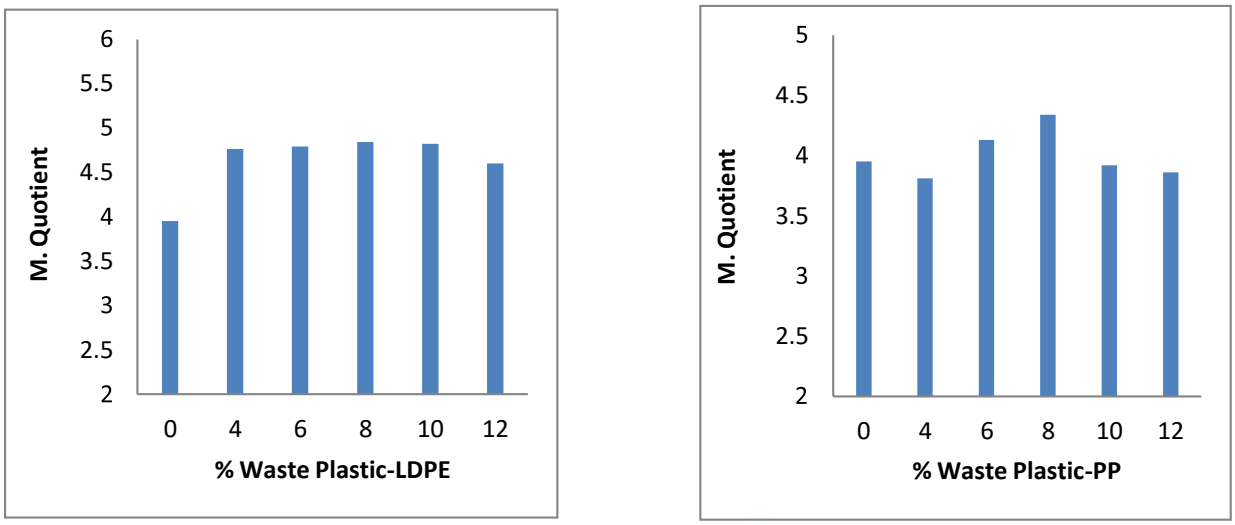


(a) (b)

Figure-4 Flow at different % Waste Plastic (a) LDPE and (b) PP

M. Quotient

The Marshall Quotient is maximum at 8% of plastic content for both the waste plastic as shown in the given Figure-5 which is higher than the conventional bituminous mix. The higher value of Marshall Quotient explains the increment in resisting the permanent deformation, rutting and shear stress. Marshall Quotient of waste plastic-LDPE modified mix is higher than the waste plastic-PP modified bituminous mix because of good adhesion between waste plastic-LDPE coated aggregate and bitumen than waste plastic-PP coated aggregate andbitumen.

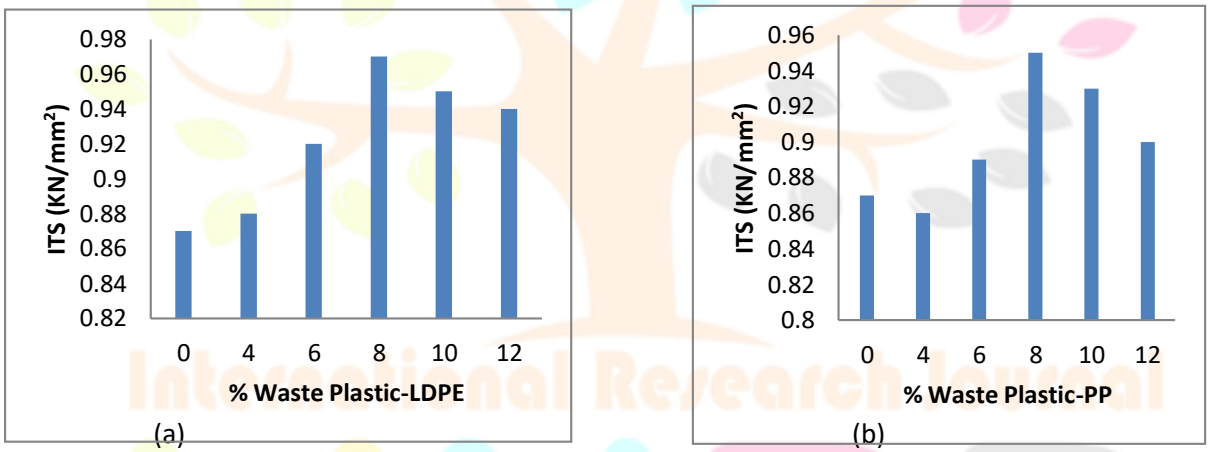


(a) (b)

Figure-5 M. Quotient at different % Waste Plastic (a) LDPE and (b) PP

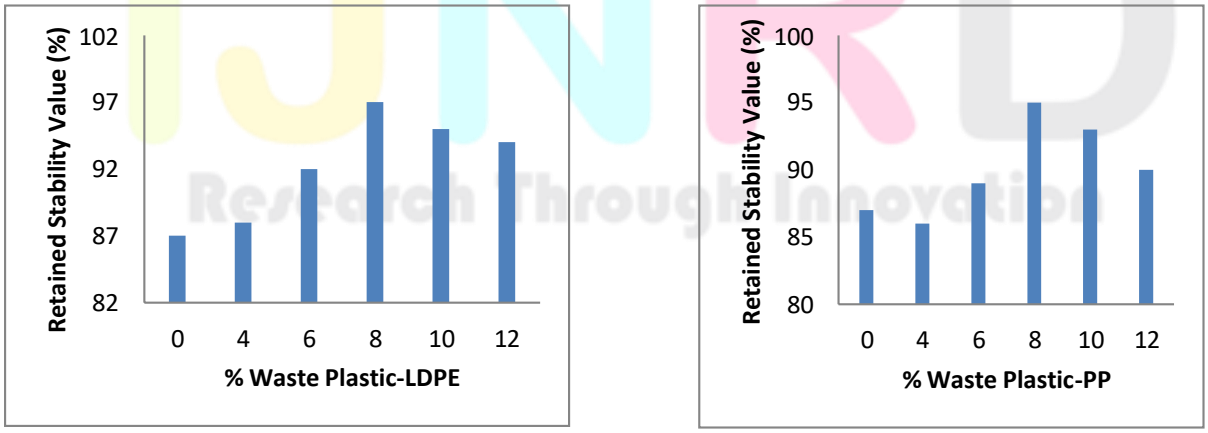
Indirect Tensile Strength (ITS)

The ITS values of modified bituminous mixes are higher than the unmodified bituminous mix as represented in Figure-6. The increased ITS values explain the improvement in resisting higher tensile strain at 8% waste plastic. The ITS value first increases up to 8% plastic content and then decreases at higher plastic content due to increase in stiffness of the mix. The ITS value of modified bituminous mix of waste plastic-LDPE is higher than the modified bituminous mix of waste plastic-PP.



(a) (b)

Figure-6 ITS at different % Waste Plastic (a) LDPE and (b) PP



(a) (b)

Figure-7 Retained Stability Value at different % Waste Plastic (a) LDPE and (b) PP

Retained Stability Value

The Retained stability values of modified bituminous mixes are more than the conventional bituminous mix. The variation of Retained Stability is shown in given Figure-7. Retained Stability increases up to 8% plastic Content and then decreases at higher plastic content it is because the adhesion between plastic coated aggregate and bitumen becomes weaker at higher % of plastic content. The higher Retained Stability shows the improve moisture susceptibility of modified bituminous mixes. The Retained Stability for modified bituminous mix of waste plastic-LDPE is higher than modified bituminous mix of waste plastic-PP because the adhesion of LDPE and bitumen is better than the adhesion between PP and bitumen.

Conclusions

In this study waste plastics (Milk Pouch & Biscuit Cover) were used to modify the bituminous mixes of grade-II. Dry process was adopted for the addition of waste plastics and many mechanical properties like Marshall Stability, Flow Value, Marshall Quotient, Retained Stability and Indirect Tensile Strength (ITS) were calculated. Marshall Stability, Flow and Marshall Quotient are 44.95%, 24.31% and 22.22% for waste plastic- LDPE (Milk Pouch) and 26.71%, 15.7% and 9.6% for waste plastic-PP (Biscuit Cover) are more than the conventional bituminous mixes at 8% of waste plastic. Increase in flow value represents the improvement in elastic behaviour of bituminous mixes. Retained Stability value is 11% and 8.7% more than the conventional bituminous mix at 8% waste plastic which shows improve adhesion among plastic waste blended aggregate and asphalt. Indirect Tensile Strength (ITS) value is around 11% and 8.7% more than the conventional bituminous mix at 8% waste plastic. The optimum amount of waste plastic was 8% for both the waste plastic which fulfils the requirement for mechanical properties of an ideal modified bituminous mix. Hence, utilization of waste plastic in black top road using a dry process is environmental friendly solution with the following advantages:

a. Higher percentage of waste plastic can be used.
b. Avoid disposal of waste plastics through incineration and landfill.
c. Cost of road can be decreased by replacing some quantity of bitumen with waste plastics.
d. Strength and Mechanical properties of the road can be increased.
e. Generate a job for ragman.
f. Develop a technology which is environment friendly.

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