PERFORMANCE EVALUATION OF BITUMINOUS CONCRETE INCORPORATING CRUMB RUBBER AND WASTE SHREDDED THERMOPLASTICS

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Abstract

Increase in environmental concerns has been leading to develop innovative and eco-friendly ideas to re-use the waste byproducts from industries and domestic use. Waste plastic and waste tyres/crumb rubber considered as solid waste in India which causes environmental pollution. These wastes will be disposed by land filling and incineration which are hazardous. Plastic is user friendly but not eco-friendly. In this present study waste plastic and crumb rubber has been used to modify the conventional bituminous mix. This modifier raw-material has been sourced from disposed waste plastic and crumb rubber. This provides a solution towards ecological menace posed by increased use of plastic. Incorporation of waste plastic which is mainly consists of LDPE had been done by "dry process"; an in-situ process which can be practiced locally. In this process addition of plastic has been done by replacing bitumen by percentage by weight in varying percentage. Marshall Method of bituminous mix design was carried out. Significant improvement in properties like Marshall Stability, retained stability, indirect tensile strength has been observed in waste plastic bituminous mix compared to conventional mix.

***Keywords**: waste thermoplastic, bituminous mix, Marshall Properties, ITS, retained stability*

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1. INTRODUCTION

The growth in various types of industries together with population growth has resulted in enormous increase in production of various types of industrial and domestic waste materials world over. Especially disposal of domestic solid waste which mainly consists of polyethylene carry bags and waste tires from automobiles which are non bio-degradable in nature causes environmental problem. Plastic is user friendly but not eco friendly. These waste materials are disposed by either land filling or incineration. Both the process has certain impact on environment, and to overcome these disposal problems it is necessary to find the way for safe disposal of these waste materials. Recycling is the common solution for these disposal problems. Recent developments in technologies and researches have been proving there are several successful ways to re-use these so called waste materials. One of the solutions is use of these waste materials in road construction. Considerable research has been carried out to determine suitability of these waste thermoplastics as a modifier in construction of bituminous mixes [1-4]. The use of recycled plastics composed predominantly of polypropylene and low density polyethylene in plain bituminous mixtures increases the durability and improved fatigue life[5]. The use of waste polymeric packaging material in bituminous mix reduces the rutting and low temperature cracking of pavement surface [6]. Previous investigation shown that waste thermoplastics and copper slag can be use for low cost road construction [7] The use of waste plastic and crumb rubber in flexible pavement results in increasing strength up to 25%[8]. The performance of thermoplastics modified bituminous concrete mix shows less susceptible to deformation and improvements in stability, ITS and retained stability of modified mix compared to the conventional mix.

In this present study comparison has been drawn between the properties of bituminous mix prepared by using penetration grade 60/70 bitumen and commercially available crumb rubber modified bitumen (CRMB55) and also the mix modified by using waste thermoplastic by replacing some percentage of bitumen by 'dry process'.

2. MATERIALS AND METHODS

2.1 Materials

In this study 60/70 penetration grade bitumen and commercially available crumb rubber modified bitumen (CRMB55) from the local manufactures has been used and their properties are given in Table 1 and Table 2.

Table 1 Physical properties of 60/70 bitumen

Properties	Test method	Value
Penetration (mm)	IS:1203	67
Softening point 0C, R&B	IS:1205	49
Ductility at 270 C, 5 cm/min	IS:1208	+75
Specific gravity	IS:1208	1.03

Table 2 Physical properties of CRMB 55

Properties	Test method	Value
Penetration (mm)	IS:1203	55
Softening point 0C, R&B	IS:1205	55
Ductility at 270 C, 5 cm/min	IS:1208	+100
Specific gravity	IS:1208	1.02

Aggregate from local quarry (quartzite type) is used for the preparation of bituminous mixes. The results of physical properties of aggregates are given in Table 3.

Table 3 Physical properties of aggregate

Properties	Test method	Value
Impact value (%)	IS:2386 Part 1V	25.05
Crushing value (%)	IS:2386 Part 1V	22
Specific gravity	IS:2386 Part 1V	2.665
Water Absorption	IS:2386 Part 1V	0.3

Grading of aggregate as per Ministry of Road Transport and Highways Specification (MoRT&H) for bituminous concrete (Grading 2) The selected gradation and specification limits are shown in Table 4 and Fig. 1.

Table 4 Aggregate Gradation as per MORT&H Specification for Bituminous Concrete Mix (Grading-2)

Sieve size (mm)	% passing specified	% passing adapted
19	100	100
13.2	79-100	89.8
9.5	70-88	72.7
4.75	53-71	68.8
2.36	42-58	56.9
1.18	34-48	40.8
0.6	26-38	27
0.3	18-28	19.8
0.15	12-20	12.7
0.075	04-10	9

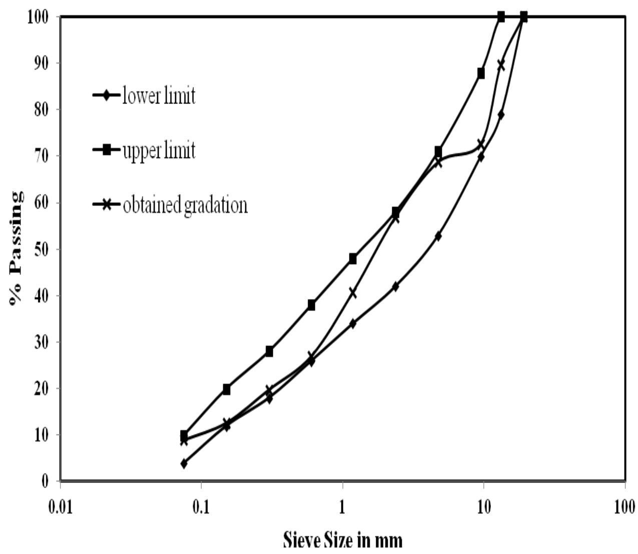

Fig. 1 Gradation curve

For the present study different domestic plastic waste mostly containing low density polyethylene, polyethylene polypropylenes are used. The cleaned waste plastic shredded to size 2.36 mm to 4.75 mm using shredding machine.

2.2 Methods

Bituminous mixes for this study were prepared in a mixing pan. For preparation of mixes, aggregate was heated to 175°C and bitumen to 160°C. Aggregate was taken in a pan and requisite quantity of bitumen was then added to heated aggregate and both the ingredients were mixed vigorously using a spatula. For bituminous mix prepared using CRMB 55 binder as per IRC-SP-53-1999 the binder should be heated to170^0-180^0 C. In case of shredded waste thermoplastics modified bitumen was replaced by shredded waste thermoplastics was added to aggregate before mixes, some percentage by weight of adding the bitumen at 175°C in and mixed for not less than thirty seconds followed by addition of bitumen heated to 165°C .

2.3 Testing of Mixes

The properties of Marshall Specimens as per MORT&H are given in Table 5. For testing of stability, flow, indirect tensile strength (ITS), marshall specimen of 101.3 mm diameter and 63.5 mm height using 75 blows on both sides were prepared by standard rammer at 155°C as per procedure described in ASTM D 1559. The optimum binder content for both mixes are determined and the properties of mixture at OBC is given in Table 6. The results of stability, flow, Marshall quotient (stability/flow), indirect tensile strength (ITS) along with methods of test adopted are given in Table 7. Volumetric and engineering properties of mixes at varying shredded waste thermoplastics content are given in Table 7. ITS and Retained stability test was conducted on Marshall samples of conventional bituminous mix as well as modified mixes at 25ºC.

Table 5 MORT&H Specification

Properties of Marshall Specimens	Specification Limits
Marshall Stability value (kg)	Min 900
Marshall Flow value (mm)	2-4
Air Voids in total mix (Va %)	3-6
Voids filled with Bitumen, (VFB %)	65-75
Voids in Mineral aggregate (VMA%)	Min 14

Table 6 Properties of mixtures at OBC

Binder	60/70	CRMB 55
OBC	5.2	5.2
Density (gm/cc)	2.371	2.373
Va %	4	4
VFB %	16.11	16.04
VMA%	74.3	74.7
Flow (mm)	3.9	3.6
Stability (Kg)	1280	1350

Table 7 Volumetric and mechanical properties of mixes at varying waste thermoplastics content

Properties	Method	Shredded waste thermoplastics (%)						
		0	2	4	6	8	10	12
Bulk density, g/cm3	ASTMD2726	2.372	2.371	2.37	2.371	2.374	2.373	2.372
Air voids, % ASTMD3203	ASTMD3203	4	4.13	4.16	4.13	4.01	4.15	4.08
voids in mineral aggregate	ASTMD3203	16.06	16.1	16.13	16.1	16	16.12	16.06
Voids filled by bitumen, %	ASTMD 3203	74.55	74.32	74.15	74.31	74.89	74.22	74.55
Marshall stability Kg, 60ºC	ASTM D 1559	1277	1332	1369	1415	1480	1425	1406
Marshall flow, mm at 60ºC	ASTMD 1559	3.8	3.9	3.7	3.9	4	4	4
Marshall quotient, kg/mm	Stab/Flow	336	342	370	363	370	356	352
Indirect tensile strength, kg/cm2, at 25°C	ASTM D 4867	9.63	9.04	9.34	10.03	10.53	9.93	9.73
Tensile strength Ratio	ASTM D 1075	82	86	86	88	94	93	93

2.4 Tensile Strength

The ITS test was performed by loading a Marshall specimen with single compressive load, which act parallel to and along vertical diametrical plane. This loading configuration develops a relatively uniform tensile stress perpendicular to the direction of the applied load along the vertical diametrical plane, which ultimately causes the specimen to fail by splitting along the vertical diameter. The load at failure was recorded and the indirect tensile strength was calculated using following equation:

$$S_t = \frac{2p}{dt} \quad (1)$$

Where, p is load (kg), d is diameter of the specimen (cm) and t is thickness of the specimen (cm).

2.5 Tensile Strength Ratio (TSR) Test

The tensile strength ratio of asphalt mixes is an indicator of their resistance to moisture susceptibility. The test was carried out by loading a Marshall specimen with compressive load acting parallel to and along the vertical diametric-loading plane. The test was conducted at 25°C temperature and the load at which the specimen fails is taken as the dry tensile strength of the asphalt mix. The specimens were then placed in a water bath maintained at 60°C for 24 h and then immediately placed in an environmental chamber maintained at 25°C for two hours. These conditioned specimens were then tested for their tensile strength. The ratio of the tensile strength of the water-conditioned specimens to that of dry specimens is the tensile strength ratio.

2.6 Retained Stability

The Marshall Immersion test was done to evaluate the resistance of mixtures against water. Specimens were made at their optimum asphalt content and immersed in the water bath for 24 hours at 60^0C and some other specimens were immersed in the water bath for 30 minutes at 60^0C too. The Index of Retained Strength (IRS) was then calculated using equation:

$$IRS = \frac{S_2}{S_1} * 100 \qquad (2)$$

Where;
S_1= Marshall Stability for specimens immersed in water bath for 30 minutes
S_2 = Marshall Stability for specimens immersed in water bath for 24 hours

RESULTS AND DISCUSSIONS

Thermal behavior of the waste thermoplastics in Table 5 shows the softening temp is about 120-160^0 C and it doesn't liberate any toxic gases in that temperature hence it can be used . Marshall mix design was conducted on conventional mixes to arrive optimum bitumen content using 60/70 bitumen and CRMB 55. For the conventional mix using 60/70 bitumen, optimum binder content obtained was about 5.2% and the Marshall stability obtained for corresponding OBC were 12.8KN. For CRMB-55 mix the obtained OBC also 5.2%, but there was an increase in Marshall stability from 12.8 to 13.5 KN compare to the conventional mix .also the Marshall flow which indicates the deformation had been gone down to 3.6 mm from 3.9 mm and the remaining volumetric properties were within the satisfactory range and it was given in Table 6.

Modification of bituminous mix was carried out by dry process using shredded waste thermoplastics of size 4.75mm - 2.36mm. In this study some calculated percentage by weight of bitumen was replaced by shredded waste thermoplastics and optimum thermoplastics content was obtained which is about 8 percentage weight of bitumen. The properties of waste thermoplastics modified bituminous mix was given in Table 7.

The indirect tensile strength which indicates the moisture susceptibility of the mix is higher in thermoplastics modified mix compare to the other two mixes. The thermoplastics/polymer modified mix by replacing 8% by weight of total bitumen required showed the higher indirect tensile strength ratio compare to the CRMB-55modified mix which indicates the low moisture susceptibility to the water or wet weather condition. The ITS ratio increased from 82 to 93 % compare to the min specified value 80%.

Retained stability test was done to evaluate the resistance of mixtures against water. Thermoplastic modified mix showed the higher stability compare to the other two mixes. The retained stability indicates the strength of the mix which is adversely soaked for about 24 hours. It is given in Table 8.

Table 8 Retained stability

Binder type	S_1 (kg)	S_2 (kg)	Retained Stability (%)
60/70 bitumen	1280	1080	84.4
CRMB 55	1350	1210	89.6
60/70 Bitumen+8%Thermoplastics	1480	1370	92.6

CONCLUSIONS

Low density polyethylene polypropylene and polystyrene are the key constituents which are used for manufacturing carry bags and other packaging materials used for domestic purpose. The modified bituminous mix shows good results when compared to conventional mix. The optimum content of waste thermoplastics to be used is 8% by weight of bitumen Use o f thermoplastics reduces the need of bitumen. Optimum binder content of the mix reduced from 5.2% to 5.1%, i.e. binder content reduced about 0.1%.Reduction in bitumen required leads to the saving of bitumen hence also the cost of construction will also decreases. Increase in the stability from 12.8KN to 14.8KN. Indirect tensile strength was significantly improved in thermoplastic blended bituminous mix. There is 8% increase in dry condition and 25% increase in wet condition compare to plain bituminous concrete. However CRMB mix showed a marginal increase in indirect tensile strength compare to that of plain bituminous concrete.

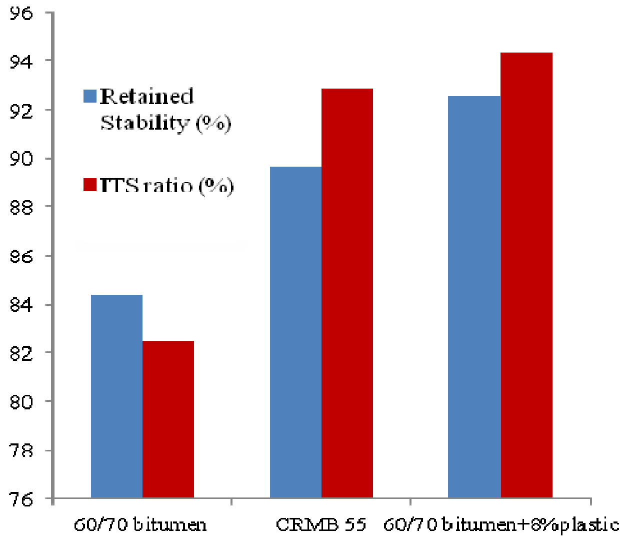

Fig. 2 ITS and Retained stability of mixes

The tensile strength ratio was about 94% for thermoplastic blended mix and it was about 82 % and 93% for plain and CRMB mix respectively. The increase in residual indirect strength were good and this can results in better performance of road even in wet weather condition due to higher crack resistance therefore better serviceability.

The use of modified bituminous mix with the addition of processed plastic by about 8.0 % by weight of bitumen helps in substantially improving the stability or strength, and other mechanical properties of bituminous concrete mix even under adverse water logging conditions. Therefore the life of the pavement surfacing course using the thermoplastic modified bituminous mix is also expected to increase substantially in comparison to the use of conventional bituminous mix.

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