INVESTIGATION ON POTENTIAL USE OF PLASTIC WASTE MATERIAL IN BITUMINOUS MIXES FOR FLEXIBLE PAVEMENT : A REVIEW

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Abstract

Use of bituminous mixes in road construction is old as Greek and Roman civilization. Properties of bituminous mixes were developed /modified with experience / understanding and development. Some of the modification in the form of filler material and use of anti- stripping agents are the recent one. Basic objectives of all these changes are to have a dense, stiff, uniform texture, durable material fulfilling the requirement of load dispersion and riding quality. Successful designing of bituminous mix with modified material is not a simple task as it requires perfect balance between various desired properties of the mix.

The challenge faced in such mix designing is that various governing parameters are interrelated and alteration in one of the parameter may affect the other parameter. Limited guidelines are available for mix design of modified bituminous mixes. A wide range of mix designing methods can be witnessed in past researches. Researchers, all over the world, have followed different techniques for mix designing of bituminous mix depending on the geographical area, where research is being carried out.

Key Words: Marshall stability, bituminous mix, nonbiodegradable, waste plastic, flexible pavement, stability.

Introduction

Plastics are a wide range of synthetic or semi-synthetic materials that use polymers as a

main ingredient. Their plasticity makes it possible for plastics to be moulded, extruded, or pressed into solid objects of various shapes. This adaptability, plus a wide range of other properties, such as being lightweight, durable, flexible, and inexpensive to produce, has led to its widespread use. Plastic can be divided into two categories-thermoplastics & thermosetting plastics. Thermoplastics have high durability, resists humidity and other harsh environments, no chemical reaction occurs during application processing. Therefore, it can be primarily used in pavement construction. Research has shown that plastic can be used for the construction of bituminous roads as well, in fact, plastics used are high-density polyethylene, polypropylene since they are inexpensive and exhibit high flexural strength and resistance to moisture. Generally, Pavement failures occur due to insufficient quality of materials or inadequate drainage, and the water seeps into the pavement layers, making the material loose and that creates potholes and many other failures. Plastics when used in pavements produce high stability, good binding property, and do not allow water to seep through it and thus become a solution for many pavement failures. According to the Guidelines on use of Plastic Waste in Road Construction by the Ministry of Railways, waste plastic of 6 to 8 percent of the weight of bitumen is used for bituminous concrete.

Marshall stability tests were performed on the mix with varying proportion of bitumen to

compare the results without plastic and to determine the optimum bitumen content Literature Review Summary:

Bituminous modification processes with natural and synthetic polymers goes back to 1843, but major utilization of these polymers in bituminous mixes was started in early 1990s. The summary on literature of some selected papers is given in Table 2.1.

Flynn (1993) studied the behaviour of bituminous mixes with addition of recycled polyethylene from grocery bag. The results show improvement in rutting resistance and low temperature cracking in bituminous mixes.

Panda and Mazumdar (1999),observed properties of binder such as penetration value, ductility value and specific gravity value decreased, whereas the softening point and viscosity increased with addition of ethylene vinyl acetate copolymer as a modifier.

Bituminous concrete mix containing 5% ethylene vinyl acetate and 6% bitumen content fulfil the requirements of an ideal mix. Stability and air voids increased and flow value and unit weight decreased with addition of ethylene vinyl acetate. The tensile strength of conventional and modified bitumen were 0.45 and 0.86 MPa respectively.

Zoorab and Suparma (2000) studied the effect of waste plastic. They replaced mineral aggregates with low density polyethylene of equal size. It is observed that in case of bituminous concrete mix, by 30% replacement of aggregates, stability value increased by 250% times as compared to conventional material. Creep stiffness of modified mix after one hour loading at 60°C was observed to be lower; whereas indirect tensile strength was more as compared to conventional mix.

Panda and Mazumdar (2002) studied the behaviour of bituminous concrete mix with modification of bitumen using low density polyethylene in the range of 2.5%, 5.0%, 7.5%, and 10.0% by weight of bitumen. Marshall Stability, fatigue life, resilient modulus, and moisture susceptibility improved with addition of low density polyethylene. Optimum dose of modifier was observed as 2.5%.

Kumar et al. (2003) observed the behaviour of recycled plastics in bituminous concrete mixes. Investigations on fatigue and indirect tensile strength have shown an improvement in modified mixes as compared to conventional mixes.

Punith and Veeraragavan (2003) observed that stability value of bituminous concrete mix containing 8% recycled plastics increased to 1.65 times as compared to plain mixes. The fatigue life of bituminous concrete mix modified with waste plastic also increased at 25ºC, 30ºC and 35ºC temperature.

Shridhar et al. (2004) observed that stability value increased by 20% with addition of waste plastics in bituminous concrete mixture. It was also observed that indirect tensile strength increased by about 30% in plastics modified mixes. Fatigue life of modified bituminous concrete mixes was twice as compared to conventional bituminous mix.

Vasudevan et al. (2006) observed that application of polyethylene and polypropylene reduced porosity and absorption of moisture.

Yildirim et al. (2007) concluded that elasticity recovery, softening point, ductility and viscosity of polymer modification bitumen was higher as compared to neat binder.

Awwad and Lina (2007) studied the effect of low and high density polyethylene on engineering properties of bituminous mixes. Better engineering properties can be achieved through high density polyethylene. Appropriate amount of the modifier was 12% by the weight of binder content. It was observed that stability, air voids and voids in mineral aggregate increased whereas density of mixture decreased with inclusion of modifier.

Awanti et al. (2008) studied effect of waste plastic made up of styrene butadiene styrene on rheological properties of bitumen and mechanical properties of bituminous concrete via wet process. Amount of styrene butadiene styrene was taken as 3.5% by weight of binder content. Value of softening point and viscosity were observed to be 16% and 98% higher, whereas the penetration was observed 36% lower for modified bitumen as compared to neat bitumen. Stability and flow parameters observed for modified mix were 56% and 39% higher as compared to normal bituminous concrete mix at optimum bitumen content. The static indirect tensile strength for modified mixes was higher in the range of 49 to101% as compared to neat mixes in 15 - 40°C temperature range. Modified bituminous mixes showed tensile strength and resilient modulus ratio14% and 19% higher as compared to neat mixes.

Hamid et al. (2008) studied the effect of styrene butadiene styrene and ethylene vinyl acetate on bituminous mixes in the range 3% to 6% (with an increment of 1%) using wet process. The recommended optimum dose of modifier was 3% by the mass of bitumen content. Strength of mixture improved with reduction in air voids.

Chen et al. (2009) observed an improvement in rutting, stiffness and temperature susceptibility of the mixture with addition of polymer. Adhesion and degree of cohesion also improved with addition of polymer in bitumen.

Hadidy and Tan (2009) studied that durability and service life bituminous mixes improved with addition of polymer in bituminous mixes. The improved properties of bituminous mix helpful for reduction of pavement layer thickness.

Shankar and Prasad (2009) concluded that Marshall’s parameter can be improved with addition of rubber. A reduction in optimum bitumen content was observed in modified bituminous mixes along with improved characteristics as compared to base mix.

Sabina et al. (2009) studied the behaviour of bituminous concrete mixes with addition of 8% and 15% plastic polymer by weight of optimum bitumen. Thermal gravimetric analysis curve shows that plastic polymers were thermally stable up to 200°C. Marshall Stability value with 8% and 15% polymer modifier mixes were 1.21 and 1.18 times higher as compared to conventional mix. For conventional mix, indirect tensile strength at 25°C was 6.24kg/cm2, while for modifier mixes at 8% and 15% it was 10.71 and 8.20kg/cm2respectively. Rutting of conventional, 8% and 15% polymer content were 2.7mm, 3.7mm and 2.7mm respectively. Durability and moisture susceptibility of modified bituminous mixes improved in actual field conditions.

Othman (2010) studied the effect of low density polyethene on bituminous concrete mixes. Additive was used as 1.5%, 3% and 4.5% of bitumen content using wet process.

Rheological properties such as softening point, kinematic viscosity and ductility increase whereas penetration decreases with addition low density polyethene. Modified bituminous mixes have higher indirect tensile and compressive strength as compared to base mixes. Optimum dose of modifier was 4.5% by weight of bitumen.

Bindu and Beena (2010) investigated the behaviour of waste plastic in bituminous concrete mixes with portland cement as filler through dry process. Waste plastic (polyethylene terephthalate) were used in the range 5% – 10% (1% increment) by weight of bitumen.

With the increase in plastic waste, stability value increases up to 10 % however flow value decreases. Marshall Stability value of modified mix at 10% plastic content was 16.82kN which was 64 % more as compared to the conventional mix. The retained stability value at

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was found to be

10% modifier was 95% whereas in conventional mix, it 79%.

Bituminous mix with 10 % plastic has 44% higher cohesion as compared to conventional mix.

Sangita et al. (2011) observed the effect of waste plastic bags in the form of low density

polyethene on bituminous concrete mix through dry process. Amount of modifier was taken

0 - value

Stability and indirect tensile strength

13

12% by weight of bitumen.

in the range of

of modified mix were 1.5 and 1.54 times higher at 8% plastic content as compared to base mix. Retained stability was 95% and 85% for modified and conventional mixes respectively. Rutting resistance of waste plastic modified mixes was more as compared to neat mix.

Rasel et al. (2011) investigated the effect of polyvinyl chloride on dense bituminous macadam in varied range 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20% by the

weight of bitumen. Penetration ductility value and

value, flash and fire point,

14

solubility value decreases with the increase of polyvinyl chloride content in bitumen. Stability value increases up to 7.5% of waste plastic content and decreases with further

1

increase in plastic content.

Ahmadinia et al. (2011) studied mechanical

properties of bituminous concrete mixes

15

with addition of portland cement as filler and waste plastic bottles made up of polyethylene terephthalate as a modifier via dry process. Percentage of polyethylene terephthalate was

taken as 0-10% (2% increment) i.e. 5%, 5.5%, 6%, 6.5% and 7%.

1

by weight of bitumen

Volumetric and mechanical properties at 6% polyethylene terephthalate were in acceptable range.

Sangita et al. (2011) nitrile rubber and polyethylene (1:4 ratio) on the

studied the effect of

bituminous concrete mixes using dry process waste polymer (i.e.

with varied percentage of

6%, 8%, 12% and 15% of optimum bitumen content). Marshall Stability value increases by 50% at 8% waste polymer content and decrease with further increase in modifier. Marshall Quotient was 1.41 times more at 8% modifier content as compared to conventional mix.

Retained stability was maximum at 8% modifier content i.e. 94%. Indirect tensile strength at 25°C was 6.5kg/cm2 and 11.92kg/cm2 for conventional and modified mix (with 8%) respectively. Tensile strength ratio was 93.5% with 8% modifier and 89.0% for conventional mix. Creep modulus of waste polymer modifier bituminous concrete mix was

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was found to be

higher as compared to normal mix. Rutting lower for mix containing 8%

waste polymer i.e. 3.68mm as compared to 6.44mm for conventional mix. Resilient modulus at 5°C and 45°C for 8% modifier were 0.46 and 1.21 times higher

base

as compared to

mix.

Splitting tensile strength of

use of waste plastic

of plastic waste as

Konina (2011) observed low porosity in case of pavements made up

compared to concrete pavement. It is also observed that abrasion and slips resistance of pavements.

7

satisfied the specified limits.

improved modified mix

Jain et al. (2011) studied that stiffness modulus of bituminous concrete and observed an increase in it with high density polyethylene. Results reveal that optimum dose of additive

was 0.3 to 0.4% More amount of modifier was undesirable.

1

by weight of bitumen.

Rutting was reduced by addition of optimum quantity of waste polymeric packaging material in bituminous mix.

Rokade (2012) studied the effect and crumb rubber using

8

of low density polyethylene

dry and wet process. Characteristics of mix were determined using Marshal Method of mix

design by varying percentages

9

of low density polyethylene

stability value was observed with addition of low density

and crumb rubber. Higher

rubber.

Souza et al. (2012) observed an improved rutting behaviour with higher angularity aggregate because of better interlocking properties.

polyethylene and crumb

Vasudevan et al. (2012) studied thermal behaviour of polyethylene, polypropylene and polystyrene used in construction of flexible pavement. Polyethylene, polypropylene and polystyrene softened at 130 - 140°C without any evolution of harmful gases. Decomposed at 270°C and releases gases like methane, ethane etc. There was significant improvement in the physical properties aggregate coated with polyethylene, polypropylene and

1

Marshall Stability value of

polystyrene.

improvement in load bearing capacity.

modified mix was 20 kN, which indicate an

Ahmadinia et al. (2012) presented an experimental work on stone mastic asphalt with

portland cement as filler and varied bottle (Polyethylene

percentage of waste plastic

Terephthalate) ranging (with 2% increment) as a modifier. The waste plastic

from 0 to 10%

was introducing after mixing all the ingredients. Resilient modulus of modified mixes was increased by 16% at 6% PET content as compared to conventional mix. Lower rut depth was observed for 4% PET content mix, which was reduced by 29% as compared to basic mix. Drain down values of mixture containing waste plastic also reduced

1

with an

increment of

plastic content. Tensile strength ratios were above 70%, which indicate that all PET modified mixes achieved the acceptable range. The optimal range of waste plastic was 4 – 6%

studied the effect of

by weight of bitumen.

Idris and Yassin (2012) shredded low density polyethylene, as a

bitumen modifier, on the permanent deformation of bituminous concrete. The parameters assessed include compacted hot-mix density, percentage air voids, voids in mineral aggregate, voids filled with binder in addition to stability and flow value. The effect

of 1

was

10% by weight of bitumen

mixed with the

low density polyethylene on

it was found that

rheological properties was also investigated. Bitumen

low density polyethylene in the range 2 - at

160-180°C and Marshall samples prepared with the modified binder fulfil

the specified limits however using higher percentage of plastics

waste results into separation of polymer from the blend. A new technique was developed where the stone aggregates were coated with molten low density polyethylene

in the range

10-25% Waste plastics coated aggregates shows better binding

by weight of bitumen.

of

properties in terms of less water susceptibility and much less voids along with higher stability value.

1

on the mechanical properties of

Alonso et al. (2012) observed the effect of additive

bituminous concrete mixes. Water sensitivity of mixture improved with addition of additive.

Rahman and Wahab (2013) studied the behaviour of recycled polyethylene terephthalate

as partial replacement of fine aggregate

in bituminous mixture. The modified bituminous mixes were produced using 5 to 25% (by weight of bitumen)recycled polyethylene terephthalate. Samples prepared were subjected to axial loading of 100 kN for 1800 cycles for permanent deformation. Stiffness of mixes was studied using indirect tensile stiffness

modulus test at 25°C. Permanent deformation of mixes improved at 20% partial replacement of aggregate with recycled polyethylene terephthalate; however stiffness of modified mixes reduced as compare to conventional mix.

Devi et al. (2013) observed that pavement characteristics improved using waste plastic

1

of waste plastic coated aggregates

coated aggregate. Rutting behaviour compared to conventional mix.

was better as

Shankar et al. (2013) investigated the use of waste plastics for improvement of bituminous

concrete using dry process. Waste

indirect tensile strength value

11

plastic was used as

(by weight of binder content). Marshall Stability and

0%, 3%, 6%, 10%, 14% and 18%

6% of plastic content, which was 29% higher as compared to conventional mix. Tensile strength ratio at 6% plastic content was also higher as compared to basic mix. Rutting depth of conventional and modified mixes were 10.5mm and 5.5 mm after 10000 passes.

increased up to

Moreno et al. (2013) studied the behaviour of bituminous concrete mixes manufactured with crumb rubber via wet and dry process. Dose of crumb rubber was taken as 8% and 20% by weight of bitumen for wet process and 0.5%, 1.0% and 1.5% by weight of total mix

1

of crumb rubber modified

for dry process. Performances mixes

were evaluated by performing wheel tracking and cyclic triaxial test. Modified mixes shows improvement in resistance to plastic deformation.

Ameri et al. (2013) studied the behaviour of bituminous concrete mixture modified with

ethylene vinyl acetate 0 - 6% (2% increment) of optimum binder content i.e.

in the range of

5.6% and three main parameters namely rutting, fatigue damage and low temperature cracking were evaluated. Rutting performance improved with addition of ethylene vinyl acetate with respect to conventional mix. Fatigue damage of mix with modified bitumen decreased with increase in amount of modifier. Bending beam rheometer

showed that addition of ethylene vinyl acetate decreases the creep stiffness

test results

4

of modified bitumen. Resistance to low temperature cracking improved at 2% and 4% ethylene vinyl acetate modifier when compared with plain binder.

Rajasekaran et al. (2013) observed that plastic coated aggregate was better raw material for construction of flexible pavement. The process was also eco-friendly as there is no release of toxic gases.

1 in

Prasad et al. (2013) studied the suitability of polyethylene terephthalate as modifier

bituminous concrete mixes.

Bituminous concrete mixes were prepared with modifier in the range 2 – 10% (increment of 2%). Optimum bitumen and plastic content were 5.03% and

5.30% respectively. Stability value Flow value

use of waste plastic in bituminous mixes.

increased with the increase in percentage of

increased with increase in plastic content

SP 98 (2013) provides guidelines regarding

upto 5.30%. polyethylene terephthalate. IRC

Various permissible limits for characteristics applicable for modified bituminous mixes are

defined. The standard also provides using

bituminous mixes.

waste plastic in

advantages and limitations of

Shankar (2014) investigated the performance of

portland cement as filler and polyethylene terephthalate as a modifier via dry process.

with

semi dense bituminous concrete mixes

12

The size of waste plastic used was 300µ - 10mm and density was 0.95 gm/cc. Waste

plastic was used

Optimum plastic content was found to be

in the range of

1

0%, 8%, 10%, 12% and 14%

10% and 12% for SDBC mix of grade – 1 and 2

(by weight of bitumen).

respectively. Stability value of modified mixes increased up to 40% and 52% for grade - 1

and grade - 2

respectively as compared to

increased by 10% to 14% for grade 1 and

conventional mix. Indirect tensile strength

11% to 13% for grade - 2. Tensile strength ratio for conventional mixes of grade -1 and 2 92.20% and 90.02% respectively, which increases

amount of

was found to be

with increase in

waste plastic. Boiling test showed strip resistance in case of modified mix. The rut depth of modified mix was reduced by 61% and 75% for grade 1 and 2 mixes when compared with conventional mixes.

Modarres and Hamedi (2014) developed model for prediction of resilient modulus of polyethylene terephthalate modified mixes. Stiffness and fatigue characteristics of polyethylene terephthalate modified mixes were studied at 5°C and 20°C temperatures.

Polyethylene terephthalate was incorporated in the range 2-10% (2% increment) by mass of optimum bitumen content using dry mixing method. Based on the statistical analysis, it is

observed that both the developed resilient modulus and

7

models (for prediction of

fatigue life of polyethylene terephthalate modified mixes)provided good correlation with dependent variables.

Kofteci et al. (2014) investigated the performance of bitumen with addition of polyvinyl

chloride waste such as window, blinds and cable

1

The results showed that

in the range of

5% by weight of bitumen

content using wet process.

content 1%, 3%

use of plastic

and

wastes (window and blinds) up to 3% improved performance of modified bitumen at high temperatures, whereas cable waste improved the performance of bitumen at low temperatures up to

polyethylene terephthalate (PET) and

studied the effect of

5% by weight of bitumen.

of

Modarres and Hamedi (2014)

waste plastic bottles made up

styrene butadiene styrene (SBS) on the stiffness and

fatigue performance of bituminous mixes at 5°C and 20°C. was taken from 2% to 10%

at an increment of 2%, by weight of bitumen

Amount of polyethylene

terephthalate

dry process and for 4%, 5% and 6% for styrene butadiene styrene via wet process. Stiffness of mix reduces with increasing the amount of PET modifier.

9

revealed comparable stiffness and fatigue behavior

Modified mixes

10

via

However, at 5°C

for styrene butadiene styrene at 20°C. styrene butadiene styrene modified mix was slightly

higher as compared to polyethylene terephthalate modified mix.

the fatigue life of

Gonzalez et al. (2016) polyethylene, polypropylene and

1

studied the effect of

polystyrene on bituminous mixture via dry process. Stiffness of modified bituminous mixes increased as compared to conventional mixes.

were used in the range of 2,

Resistance against plastic

deformation also increased with addition of polyethylene and polystyrene.

Khan et al. (2016) studied the effect of low and high density polyethylene and crumb

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2

4, 8 and 10% by weight of

rubber on various mechanical properties of mix.

Additives

binder content. Addition of 10% low density polyethylene gives optimum rutting at different temperatures as compared to high density polyethylene and

crumb rubber. Low and high density polyethylene and crumb rubber modified bitumen

Jafar (2016) used

cross linking agent,

oxidising mixture of dichromate and sulphuric acid,

for partial replacement of

studied the effect of

reduced susceptibility to rutting and cracking.

chemical treatment on recycled waste plastic and bitumen aggregate. Waste plastics were treated with

whereas

bitumen was treated with a

a strong

3

polyethyleneeimine. The stiffness of chemically modified bituminous

mixes increased by 10%indicating improved bonding between aggregates and bitumen. Johnson et al. (2017) studied the various rheological properties of bitumen with addition of high density polyethylene and polypropylene via wet process. Amount of modifier was

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with an increment of

taken in the range 0.5 % to 3.0% 0.5%. Less value of penetration

with addition of modifier shows that hardness of bitumen increases due to addition of

modifier. Softening point both the modifier. Addition of

increased with increase in amount of

modifier increased the viscosity. Viscosity increases at a higher rate in case of high density polyethene as compared to polypropylene. The optimum dose of high density polyethylene and polypropylene were 2% and 3% respectively.

Choudhary et al. (2018) observed that polyethylene terephthalate (Size, 2.36-1.18 mm) modified mixes produced through dry method showed comparatively superior performance based on Marshall Parameters and resistance against moisture induced damage.

the effect of high density

16

Mauro et al. (2017) studied polyethene and ethylene vinyl

acetate on performance of bituminous concrete mix modified via wet and dry methods. Improvement in mechanical properties in dry process was more as compared to wet method. This can be achieved without any extra cost because dry method does not require any modified hot mix plant.

6

of dense bituminous macadam

containing

Giri et al. (2018) studied the performance mix

and pre-treated recycled concrete aggregate (PRCA) with addition of low density polyethylene via dry process.

5

1

the requirements in terms of

PRCA and RCA mixes satisfy

recycled concrete aggregate (RCA)

stability and moisture susceptibility.

Ranadive et al. (2018) waste plastic (refrigerator door panels) on

studied the effect of

stone mastic asphalt and bituminous concrete mixes in the range 4-12% (2% increment) by weight of binder. Study was carried out with varying lengths of fibres (2mm, 4mm, 6mm, and 8mm) and cement as a filler material. Initially, aggregates were heated at approximately 170°C, followed by bitumen and granular plastic at approximately 170°C. Then bitumen and plastic were mixed thoroughly and added to aggregates. Stone mastic asphalt and bituminous concrete mixes of bitumen content 5.5% and plastic content 8%

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by weight of bitumen

(length of fiber, 6mm) fulfil the requirement of modified mix.

Marshall Stability and indirect tensile strength of the bituminous mixes increased

increase in plastic content of up to

with an

6%, and decreased with a further increase in the plastic

content.

CONCLUSIONS

past researches, sufficient data is available on

utilization of plastic waste in

On the basis of

flexible pavement in the literature, but, certain gaps are also observed in the available literature. The present study aims at filling the gaps in the literature with special reference to India. The major observations in the literature are:

* Most of the work has been carried out using portland cement as filler in place of lime.
* There is limitless possibilities for waste plastic material recycling.

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waste plastic in bituminous mixes.

* Limited studies on cost implications of using

Acknowledgement

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