**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 10% modifier was 95% whereas in conventional mix, it was found to be 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 in the range of 0 - 12% by weight of bitumen. Stability and indirect tensile strength value 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 value, flash and fire point, ductility value and

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 increase in plastic content.

**Ahmadinia et al. (2011)** studied mechanical properties of bituminous concrete mixes 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) by weight of bitumen i.e. 5%, 5.5%, 6%, 6.5% and 7%. Volumetric and mechanical properties at 6% polyethylene terephthalate were in acceptable range.

**Sangita et al. (2011)** studied the effect of nitrile rubber and polyethylene (1:4 ratio) on the bituminous concrete mixes using dry process with varied percentage of waste polymer (i.e. 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 higher as compared to normal mix. Rutting was found to be 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 as compared to base mix.

**Konina (2011)** observed low porosity in case of pavements made up of plastic waste as compared to concrete pavement. It is also observed that use of waste plastic improved abrasion and slips resistance of pavements. Splitting tensile strength of modified mix satisfied the specified limits.

**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% by weight of bitumen. More amount of modifier was undesirable. Rutting was reduced by addition of optimum quantity of waste polymeric packaging material in bituminous mix.

**Rokade (2012)** studied the effect of low density polyethylene and crumb rubber using dry and wet process. Characteristics of mix were determined using Marshal Method of mix design by varying percentages of low density polyethylene and crumb rubber. Higher stability value was observed with addition of low density polyethylene and crumb rubber.

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

**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 polystyrene. Marshall Stability value of modified mix was 20 kN, which indicate an improvement in load bearing capacity.

**Ahmadinia et al. (2012)** presented an experimental work on stone mastic asphalt with portland cement as filler and varied percentage of waste plastic bottle (Polyethylene Terephthalate) ranging from 0 to 10% (with 2% increment) as a modifier. The waste plastic 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 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% by weight of bitumen.

**Idris and Yassin (2012)** studied the effect of 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 low density polyethylene on rheological properties was also investigated. Bitumen was mixed with the low density polyethylene in the range 2 - 10% by weight of bitumen at 160-180°C and it was found that 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 of 10-25% by weight of bitumen. Waste plastics coated aggregates shows better binding properties in terms of less water susceptibility and much less voids along with higher stability value.

**Alonso et al. (2012)** observed the effect of additive on the mechanical properties of 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 coated aggregate. Rutting behaviour of waste plastic coated aggregates was better as compared to conventional mix.

**Shankar et al. (2013)** investigated the use of waste plastics for improvement of bituminous concrete using dry process. Waste plastic was used as 0%, 3%, 6%, 10%, 14% and 18% (by weight of binder content). Marshall Stability and indirect tensile strength value increased up to 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.

**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 for dry process. Performances of crumb rubber modified 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 in the range of 0 - 6% (2% increment) of optimum binder content i.e. 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 test results showed that addition of ethylene vinyl acetate decreases the creep stiffness 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.

**Prasad et al. (2013)** studied the suitability of polyethylene terephthalate as modifier in 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 increased with increase in plastic content upto 5.30%. Flow value increased with the increase in percentage of polyethylene terephthalate. IRC SP 98 (2013) provides guidelines regarding use of waste plastic in bituminous mixes. Various permissible limits for characteristics applicable for modified bituminous mixes are defined. The standard also provides advantages and limitations of using waste plastic in bituminous mixes.

**Shankar (2014)** investigated the performance of semi dense bituminous concrete mixes with portland cement as filler and polyethylene terephthalate as a modifier via dry process. The size of waste plastic used was 300µ - 10mm and density was 0.95 gm/cc. Waste plastic was used in the range of 0%, 8%, 10%, 12% and 14% (by weight of bitumen). Optimum plastic content was found to be 10% and 12% for SDBC mix of grade – 1 and 2 respectively. Stability value of modified mixes increased up to 40% and 52% for grade - 1 and grade - 2 respectively as compared to conventional mix. Indirect tensile strength increased by 10% to 14% for grade 1 and

11% to 13% for grade - 2. Tensile strength ratio for conventional mixes of grade -1 and 2 was found to be 92.20% and 90.02% respectively, which increases with increase in amount of 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 models (for prediction of resilient modulus and 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 in the range of content 1%, 3% and 5% by weight of bitumen content using wet process. The results showed that use of plastic 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 5% by weight of bitumen.

**Modarres and Hamedi (2014)** studied the effect of waste plastic bottles made up of polyethylene terephthalate (PET) and styrene butadiene styrene (SBS) on the stiffness and fatigue performance of bituminous mixes at 5°C and 20°C. Amount of polyethylene terephthalate was taken from 2% to 10% at an increment of 2%, by weight of bitumen via 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. Modified mixes revealed comparable stiffness and fatigue behavior for styrene butadiene styrene at 20°C. However, at 5°C the fatigue life of styrene butadiene styrene modified mix was slightly higher as compared to polyethylene terephthalate modified mix.

**Gonzalez et al. (2016)** studied the effect of polyethylene, polypropylene and polystyrene on bituminous mixture via dry process. Stiffness of modified bituminous

mixes increased as compared to conventional mixes. 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 rubber on various mechanical properties of mix. Additives were used in the range of 2, 4, 8 and 10% by weight of 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 reduced susceptibility to rutting and cracking.

**Jafar (2016)** studied the effect of chemical treatment on recycled waste plastic and bitumen used for partial replacement of aggregate. Waste plastics were treated with a strong oxidising mixture of dichromate and sulphuric acid, whereas bitumen was treated with a cross linking agent, 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 taken in the range 0.5 % to 3.0% with an increment of 0.5%. Less value of penetration with addition of modifier shows that hardness of bitumen increases due to addition of modifier. Softening point increased with increase in amount of both the modifier. Addition 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.

**Mauro et al. (2017)** studied the effect of high density 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.

**Giri et al. (2018)** studied the performance of dense bituminous macadam mix containing recycled concrete aggregate (RCA) and pre-treated recycled concrete aggregate (PRCA) with addition of low density polyethylene via dry process. PRCA and RCA mixes satisfy the requirements in terms of stability and moisture susceptibility.

**Ranadive et al. (2018)** studied the effect of waste plastic (refrigerator door panels) on 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% (length of fiber, 6mm) by weight of bitumen fulfil the requirement of modified mix. Marshall Stability and indirect tensile strength of the bituminous mixes increased with an increase in plastic content of up to 6%, and decreased with a further increase in the plastic content.

**CONCLUSIONS**

On the basis of past researches, sufficient data is available on utilization of plastic waste in 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.
		- Limited studies on cost implications of using waste plastic in bituminous mixes.

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**References**

Flynn, E., (1993). “Recycled Plastic Finds Home in Asphalt Binder”, Journal, Roads and Bridges Vol. 58, No. 02, pp 41-48.

Giri, J. P., Panda, M., and Sahoo, U. C., (2018). “Performance of Bituminous Mixes Containing Treated Recycled Concrete Aggregates and Modified by Waste Polyethylene” Journal of Materials in Civil Engineering, Vol. 30, No. 08, pp 1- 11.

Zoorab, S. E., and Suparma, L.B., (2000). “Laboratory Design and Performance of Improved Bituminous Composites Utilizing Recycled Plastics Packaging Waste”, Presented at Technology Watch and Innovation in the Construction Industry, PalaisDescongres, Brussels, Belgium 5-6, pp 203-209.

Panda, M., and Mazumdar, M., (2002). “Utilization of Reclaimed Polyethylene in Bituminous Paving Mixes”, Journal of Materials in Civil Engineering, Vol. 14, No. 06, pp 527-530

Punith, V. S., and Veeraragavan, A., (2004). “Fatigue Characteristics of Recycled Plastics Modified Bituminous Concrete Mixes”, Highway Research Bulletin, Indian Road Congress, No. 70, pp 11-30.

Kumar, M., and Goyal, T. K., (2011). “Comparative Study of up-gradation of Highway”, Indian Highways, Vol.39, No.11, Indian Road Congress, pp 1-7.

Kumar, P., Sangita, Bose, S., and Singh, M.P., (2003). “Development of High Performance Bituminous Mixes with Recycled Plastic Waste”, Highway Research Bulletin, No. 69, Indian Road Congress, pp 29-44.

Shridhar, R., Bose, S., Kumar, G., and Sharma, G., (2004). “Performance Characteristics of Bituminous Mixes Modified by Waste Plastic Bags”, Highway Research Bulletin, No. 71, Indian Road Congress, pp 1-10.

Vasudevan, R., Saravanavel, S., Rajasekaran, S., and Thirunakkarasu, D., (2006). “Utilization of Waste Plastics in Construction of Flexible Pavement”, Indian Highways, Vol.34, No.07, Indian Road Congress, pp 5-20.

Vasudevan, R., Sekar, A. R. C., Sundarakannan, B., and Velkennedy, R., (2012) “A technique to dispose waste plastics in an ecofriendly way - Application in construction of flexible pavements” Construction and Building Materials 28 @ Elsevier Ltd. pp 311- 320.

Xiao, F., and Amirkhanian, S. N., (2008). "Effects of binders on resilient modulus of rubberized mixtures containing RAP using artificial neural network approach". Journal of Testing and Evaluation, Vol. 37, No. 02, pp 1–10

Ranadive, M. S., Hadole, H. P., and Padamwar, S. V., (2018). “Performance of Stone Matrix Asphalt and Asphaltic Concrete Using Modifiers” Journal of Materials in Civil Engineering, Vol. 30, No. 01, pp 1-9.

Rasel, H. M., Rahman, M. N., and Ahmed, T. U., (2011) “Study of Effects of Waste PVC on the Properties of Bituminous Mixes” Journal of Physical Sciences, Engineering and Technology, ISSN: 2229-7111, Vol. 02, No. 02, pp 17-23.

Rokade, S., (2012). “Use of Waste Plastic and Waste Rubber Tyres in Flexible Highway Pavements” International Conference on Future Environment and Energy, Vol.28, IACSIT Press, Singapore, pp 105 – 108.

Sabina, Khan, T. A., Sangita, Sharma, D.K., and Sharma, B.K., (2009) “Performance evaluation of waste plastic / polymer modified bituminous concrete mixes” Journal of scientific and Industrial Research Vol. 68, pp 975-979.

Sangita, Gupta, R., and Kaur V., (2011). “A Novel Approach to Improve Road Quality by Utilizing Plastic Waste in Road Construction” Journal of Environmental Research And Development Vol. 05, No. 04, pp 1036-1042