Characterization of Bitumen Mixed with Plastic Waste

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Abstract

Plastic (Polyethylene Terephthalate, PET) is now used as packaging material for a whole range of consumer products in addition to carbonated beverages. Although plastics are very useful product, but the disposal of these wastes has become a problem and is of great concern, particularly in our country. One of the solutions to the disposal of plastic wastes is recycling it into useful products such as it may be used in bituminous (asphaltic) pavements construction, resulting in reduced permanent deformation in the form of rutting of the pavement surface. The present study discusses in detail about the effect of PET on various engineering properties of bitumen. The PET waste was added in the bitumen from 2 to 14% and various tests such as penetration, ductility, softening point, viscosity, flash and fire point and stripping tests were performed for the characterization of plain bitumen and PET modified bitumen. The most effective percentage of Polyethylene Terephthalate (PET) waste was obtained between 10 to 12% by weight of the bitumen. The results of the study indicated that the modified mixture possessed better performance as compared to the non-modified bitumen. The experimental results were also authenticated by conducting Scanning Electron Microscopy (SEM) on the most effective percentages mixtures. It is observed that the addition of PET waste in the bitumen improves its engineering properties such as ductility, penetration, softening point and viscosity values by 32.43%, 14.56%, 26%, and 34% respectively. It has also been observed that addition of 12% PET waste results in zero percent stripping even after 48 hours.

Keywords: Bitumen, characterization, PET, SEM

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1. Introduction

Due to increase in population, urbanization, development activities, and changes in life style, there is an enormous rise in the generation of plastic wastes which in turn makes the solid waste management as one of the major environmental concern worldwide. These plastics are disposed in an uncontrolled manner, because of the noticeable rapid depletion of sites available for waste disposal, causing major environmental problems [Pimpan et al. 2003]. It has been estimated that the plastic (a non bio-degradable material) can remain on earth for 4500 years without degradation. The health hazard includes reproductive problems in human and animal, genital abnormalities etc. The animals feeding the contaminated vegetation are victims of skin diseases and dental disorders. The effect of this waste is found on local vegetation too. Moreover, the hazardous effect of waste is also posing threat on the population of birds and water animals [Gawande et al. 2012].The recycling of plastic wastes and by-products for use as construction materials is an important part of achieving a sustainable environmental friendly society.

Flexible pavements constitute over 90% of road network in India. The increased volume of traffic, overloading of axles beyond permissible limits and higher tyre pressure, are causing widespread problems addressed to performance of flexible pavements in India. The statistics of various performance studies indicate that useful life of bituminous overlay with traditional non-modified binders has declined from average value of 6-8 years in the past to about 3-5 years in recent years. It is well known that under the prevailing heavy traffic and extreme climatic conditions, overlays made up of traditional bituminous binders, in general, are not meeting the durability requirements. On the other hand polymer modified bitumen (PMB) known as higher performance binder, allows the engineer to design and build durable bituminous surface. These binders, as proven all over the world, have better field performance, and are economical, when life cycle cost is taken into consideration.

Performance of bituminous mixtures used for surfacing in flexible pavements, can be improved by incorporating suitable additives to bitumen. These additives include commercial materials, by products and even processed waste materials. Re-cycled plastics, mainly polyethylene, can be used in the manufacture of polymer-modified asphalt cement or bitumen. Re-cycled polyethylene from grocery bags in bituminous pavements resulted in reduced rutting and low temperature cracking of the pavement surfacing [Ranadive and Tapase, 2012].

Many studies on application of plastic wastes in the construction of flexible pavement are available such as Flynn (1993), Rahman et al (2013), Ravi et al (2013), Mohammed and Patil (2014), which stated that roadways have a high potential for utilization of large volume of the plastic waste. In these studies, an attempt has been made to investigate the use of plastic waste in the construction of bituminous road. A series of tests were performed on specimens prepared with plastic waste and bitumen. Results show that the increase in percentage of polymer causes reduction in the penetration and ductility value. Rokade (2012) studied the use of plastic waste and waste rubber tyres in flexible pavements. The Semi Dense Bituminous Concrete (SDBC) was prepared by Marshall Method using VG-30 grade bitumen and the various mix design characteristics were calculated. The author observed that with 5% bitumen content higher value of Marshall Stability and greater density was achieved. Ranadive and Tapase (2012) conducted an experimental program to study the improvement in the strength of flexible pavement, by adding plastic waste in different percentages. The authors observed that 10% of bitumen can be replaced by plastic waste in bituminous layer.

From the review of the previous literature it has been found that the studies were mainly limited to use of maximum 10% of plastic waste [Vidula et al, 2012]. However, the present study encourages the use of 12% PET waste, which ensures more utilization of waste as compared to the PET utilization in previous studies. Whereas, the studies on the variation of the plastic waste on parameters like penetration, ductility, viscosity, softening point, flash and fire points and stripping value of bitumen is limited. Hence, this study aims to utilize post-consumer Polyethylene Terephthalate (PET) waste beverage bottles by mixing it with bitumen,

which can subsequently be utilized for highway engineering works.

2. Test Materials

In this study, the materials used are:
(i) Bitumen
(ii) PET waste

2.1 Bitumen

The bitumen used in this investigation was provided by Public Work Department (PWD), Aligarh (U.P), India. The bitumen used in the present study was classified as VG-30 which is known as viscosity grade as per ASTM D-3381, equivalent to 60/70 penetration grade bitumen. The specific gravity of the bitumen is 1.021. It is used as a binder in the present work. The chemical and physical properties of bitumen are given in Tables-1 and 2, respectively.

2.2 Polyethylene Terephthalate Waste (PET)

Polyethylene Terephthalate (PET) a plastic from the family of polyesters, is nowadays being used mainly in the food industry for packaging soft drinks, mineral water, milk, oil, bakery products, frozen foods, salad dressings, cosmetics, cleaner and many other products. PET wastes were collected from local dump sites. Collected waste materials were washed with soap and water and cut into tiny pieces of size 3 to 5 mm
[Fig. 1]. The properties of PET used are given in Table-3.

3. Sample Preparation

The modifier is blended with the base binder so that it disperses thoroughly prior to use. First of all the bitumen is heated until it became liquid. The molten bitumen was poured into seven different pans with a volume of 800 ml. The PET waste in percentages of 2, 4, 6, 8, 10, 12 and 14% by weight of bitumen was added to bitumen and the mixture was heated up to 160^0 C till it attains homogeneity. The bitumen and PET waste was mixed thoroughly by using bitumen stirrer. Immediately after mixing the various properties such as viscosity, softening point, penetration, ductility, flash and fire point and stripping value tests of control and modifies specimens were determined as per the test conditions given in Table-4.

4. Testing

The following characterization tests on plain and PET modified bitumen were conducted, and the results are being discussed in subsequent sections:

4.1 Penetration Test

The test determines the hardness of bitumen by measuring the depth (one tenths of a mm) to which a standard, and loaded needle will vertically penetrate in 5 seconds, in a sample of bitumen maintained at a temperature of 25°C. The test was carried out in accordance with the procedure laid down in IS: 1203–1978.

4.2 Ductility Test

The Ductility test is an empirical test which measures the cohesive strength of bitumen and its ability to stretch. The test was conducted as per IS: 1208–1978.

4.3 Softening Point Test

The softening point is an empirical test and denotes the temperature at which bitumen would behave more like a liquid and less like a solid under standard conditions of heating and loading. The test was conducted as per IS: 1205–1978.

4.4 Viscosity Test

Viscosity is a fair indicator of the ability of bitumen to coat the aggregates properly. In order to get best coating the viscosity has to be optimum. Too viscous bitumen would result in inadequate and non-uniform coating of the aggregates. Very low viscosity would again result in inadequate coating as the bitumen will tend to bleed. Therefore, viscosity at 135° C is a true reflection of the quality of bond that is likely to be formed with the aggregate. The test was conducted as per IS: 1206–1978 by using tar viscometer with 10 mm orifice.

4.5 Flash and Fire Point Tests

Bituminous materials leave out volatile gases at high temperatures depending upon their grade. These volatile vapours catch fire causing a flash. This condition is very hazardous and it is therefore, essential to check this temperature for each bitumen grade, so that the paving engineers may restrict the mixing or application temperatures well within the limits. The tests were conducted as per IS: 1209–1978.

4.6 Stripping Value Test

In order to study the suitability of road aggregates for bituminous road construction, it is desirable to study the displacement characteristics of the binders from the aggregates by water. To determine the stripping value the static immersion test was conducted as per IS: 6241–1998.

5. Results and Discussions

The results of various tests conducted on bitumen and bitumen–PET waste blend are presented and discussed to bring out the effect of waste on penetration, ductility, viscosity, softening point, flash and fire point and stripping values.

5.1 Effect of PET on Penetration Values of Bitumen

Figures 2 and 3 and Table-5 shows the variation of penetration value of PET modified bitumen with respect to plain bitumen (PB). It shows that the consistency and penetration values of plain bitumen decrease on increase of the PET content. The decrement is about 2.55, 4.20, 8.11, 10.81, 13.96 and 14.56% with the addition of 2, 4, 6, 8, 10, 12 and 14% of PET respectively, as compared to the plain bitumen. The results also show that the addition of PET makes the modified bitumen harder and more consistent than plain bitumen which results in improvement in the rutting resistance of the mix. This mix can be suitably used in hotter climatic conditions, specially in the regions where temperature differential is substantially higher.

5.2 Effect of PET on Ductility of Bitumen

Figure 4 shows the effect of PET on ductility value of bitumen and Figure 5 shows the variation of ductility values with the various percentages of bitumen modified PET. The observation data shows that ductility of plain bitumen increases with the addition of PET. The increase in the ductility values were observed as 6.76, 10.81, 18.92, 22.97, 28.38 and 32.43% on addition of PET from 2-12% respectively, as compared to the plain bitumen, whereas, the ductility value declines at 14% PET addition. The increase in the ductility value may be due to interlocking of polymer molecules with bitumen, while decline in ductility value after 12% might be due to excess plastic waste which makes bitumen stiffer. The increase in the ductility values improves the workability of bituminous concrete and ensures the uniform coating of aggregates which results a better striping resistance of stone aggregates.

5.3 Effect of PET on Softening Point of Bitumen

The softening point is a measure of the temperature at which bitumen begins to show fluidity. Figures 6 and 7 show that softening point increases with increasing PET content. The results clearly show that the addition of PET in the bitumen increases the softening point value from 45^0 C for plain bitumen to 56^0 C for PET modified bitumen. It has also been observed that the increase in the softening point of plain bitumen was significant when PET is added in percentages from 10 to 14%. The increment in the value indicates that the resistance of the binder to the effect of heat is increased and it will reduce its tendency to soften in hot weather. Thus, with the addition of PET the modified binder will become less susceptible to temperature changes. The study carried by Fernando and Guirguisl (1984), indicated that in case of hot rolled asphalt the rate of rutting in the wheel tracking test at 45°C was halved when softening point increased by approximately 5ºC.

5.4 Effect of PET on Viscosity of Bitumen

Figure 8 shows effect of PET on viscosity of bitumen and Figure 9 shows the variation in viscosity with the addition of PET, respectively. It is observed that on addition of PET the viscosity of plain bitumen increases [Fig. 8]. The increase in the viscosity value is found to be significant when PET is added upto 12%, afterwards, it becomes almost constant [Fig. 9]. It has also been observed that the increase in the viscosity values after addition of PET in the plain bitumen was upto the order of 33 to 34%, which indicates that the modified binder became neither too soft nor too viscous, as it was observed that if the viscosity of bitumen is too high, the binder may not completely coat the aggregate in the bituminous mixture. On the other hand if it is too low, binder drainage is likely to occur during the storage and transportation of the mix. On the basis of the present study it can be said that the PET modified bitumen may have better workability as compared to plain bitumen.

5.5 Effect of PET on Flash and Fire Point of Bitumen

Flash and fire point of VG-30 bitumen is generally

observed between 230 to 250° C. From the present investigation it has been observed that the inflammability of the blend (PB+2-14% PET) decreases as the percentage of PET increases [Figs. 10 and 11]. It has also been observed that the flash point value of plain bitumen was increased by more than 30% when PET was added beyond 10%. The similar trend was also observed in case of fire point [Figs. 12 and 13]. The value of fire point significantly increases up to 12% of PET, whereas, a slight decline in the value was observed at 14% PET. The trend shows that the addition of 12% PET in plain bitumen may work efficiently to resist the burning hazards.

5.6 Effect of PET on Stripping Value

The stripping value test was conducted on plain bitumen and the most effective percentages of PET (8, 10 and 12%) with bitumen and the results are given in Tables-6 to 9. It has been observed that addition of 12% PET waste results in zero percent stripping even after 48 hours. The decrement in the stripping value of plain bitumen modified with 12% PET waste is 100%, which shows that the blend has better resistance against weathering action. Hence, the bituminous concrete modified with PET waste may open up the avenues for its use in low lying areas and regions subjected to high rainfall where bituminous construction has generally been avoided.

The results of the present study have been compared with results obtained by Vidula et al (2012) as shown in Table-10. It is found that the results of the present study with 12% PET waste are similar to the results reported by Vidula et al with 10% PET waste. It has also been observed from Table -10 that the viscosity, softening point, flash point and stripping values are better than the values reported in the cited work. Hence, this study proved to be effective in utilizing 2% more PET waste than the previous work without compromising the quality of the bitumen-PET mix.

5.7 Scanning Electron Microscope (SEM) For Microstructural Analysis of Bitumen/ Modified Bitumen

The scanning electron microphotograph (SEM) analysis was carried out to study the morphology of some of the selected samples.The SEM was carried out at University Sophisticated Instrumentation Facility, AMU, Aligarh, using a JEOL JSM-6510W with a LaB6 filament.

Figure 14 shows the scanning electron micrograph (SEM) of plain bitumen. The micrographic observation for bitumen indicates the presence of cracks on the surface, this indicates that bitumen was lacking in ductility results inimproper coating on the aggregates, which is prime reason of the pavement failure.

Figure 15 illustrates the SEM-micrograph of bitumen+10% PET. It can be observed from the figure that the PET waste was mixed uniformly with bitumen and forming a homogeneous mixture which checks the cracks.

Figure 16 illustrates the SEM-micrograph of bitumen with 12% PET. The figure shows that surface properties of mix has been improved with the addition of 12% PET but, no major changes were observed.

Figure 17 demonstrates the SEM-micrograph of bitumen+14% PET. The icrographic observation for bitumen with 14% PET indicates presence of spherical, sub rounded and irregular particles in abundance, which might be due the addition of 14% PET in bitumen causing excess PET waste which results in the agglomeration of the waste.The SEM analysis is in conformity with the test results specially when PET waste was added more than 12%.

6. Conclusions

The aim of the study was to utilize the waste materials i.e. PET wastes for mass scale utilization such as in highway construction in an environmentally safe manner. An attempt was made to assess the stabilization of the bitumen with PET waste in shredded form by performing basic tests such as Penetration, Ductility, Softening Point, Viscosity, Flash and Fire Point and Stripping Values Tests. Some of the significant conclusions and observations emerging from the present study are given below:

- The present stabilization process is very effective in controlling the environmental pollution, because the waste materials were completely recycled without any adverse impact on the environment. This study also encourages the mass scale utilization of PET waste for Highway Engineering Applications.
- The results of the study indicated that the modified mixture have a better results

compared to the non-modified mixture. By adding Polyethylene Terephthalate (PET) to the bitumen a better binding between binder and aggregates was obtained.

- The VG-30 viscosity grade bitumen was chosen and it was modified with different percentage of PET from 2 to 14%. On the basis of different laboratory tests the most significant percentage of PET as bitumen modifier was in the range of 10-12% by the weight of binder content.
- The increment in the ductility values were observed as 6.76, 10.81, 18.92, 22.97, 28.38, 32.43% on addition of PET from 2-12% respectively, as compared to the plain bitumen, whereas, the ductility value declines at 14% PET addition.
- The penetration values of plain bitumen decrease on increase of the PET content. The decrement was about 2.55, 4.20, 8.11, 10.81, 13.96 and 14.56% with the addition of 2, 4, 6, 8, 10, 12 and 14% of PET respectively, as compared to the plain bitumen.
- It has been observed that the increase in the softening point of plain bitumen was significant when PET is added in percentages from 10 to 14%. The percent increase in softening point values were about 24.40 and 26.00% after addition of PET at 12 and 14% respectively in plain bitumen.
- The increase in the viscosity value is found to be significant when PET is added up to 12%, afterwards, it becomes almost constant. It has also been observed that the increase in the viscosity values after addition of PET in the plain bitumen was up to the order of 33 to 34%, which indicates that the modified binder becomes neither too soft nor too viscous after addition of waste.
- The results of flash and fire point show that the addition of 12% PET in plain bitumen may work efficiently to resist the burning hazards.
- It has been observed that addition of 12% PET waste results in zero percent stripping even after 48 hours. The decrement in the stripping value of plain bitumen modified with 12% PET waste is 100%. This shows that the blend has better resistance against weathering action.
- The results obtained by various tests on modified bitumen were substantiated by SEM analysis. The results of SEM were very encouraging in terms of trends observed by tests, particularly in case of ductility test in which the PET inclusion after 12% reduces the ductility. The SEM analysis also confirms the test results of bitumen+14% PET which shows the agglomeration of PET particles affecting the consistence of the mix.

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