Evaluation for structural integrity of waste plastic cup modified bituminous mix by micro-chemical analysis

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Abstract: Recent market strategy delineates that cost of readymade polymer modified bitumen (PMB) is so lofty that it cannot be affordable in inexpensive roads. Therefore, in the sustainable development era several approach had found that blending of polypropylene made waste plastic cup to the bituminous mix in wet process reduced the optimum binder content (OBC) of such mix. Whereas reason behind it is remain unexplored till date and this issue is considered as a state of art investigation. However Fourier transform infrared (FTIR) micrograph and optical micrograph of waste plastic cup mixed bitumen in microscale shows that 1% of such waste by weight of bitumen enhance the adhesive property of the bitumen. Further determination of dynamic Young’s modulus (E) of bituminous mix by ultrasonic pulse velocity (UPV) test reveals that, due to incorporation of cited percentage to such mix satisfactory structural integrity has been found but beyond such limit that mix becomes brittle.

Keywords: PMB, waste plastic cup, FTIR, optical micrograph, UPV.

I. Introduction

Recent market strategy delineates that cost of readymade polymer modified bitumen (PMB) is so lofty that it cannot be affordable in inexpensive roads. Several efforts also demonstrated clearly about the high price value of the crude polymers used conventionally for making PMB. Meanwhile, a few approaches demonstrated that polymeric municipal solid wastes (MSW) are the huge feedstock of those raw polymer used for enhancing the properties of virgin bitumen. Therefore, in the sustainable development era such wastes are being experimentally devoured to improve the quality of bituminous mix in great extent throughout the globe in wet process. But all those efforts suggested different dosing percentage of PC in base bitumen varying from 0.5 to 5 wt% in wet process. Due to such fact PMB made of plastic cup is not commercialized till date. Therefore an effort suggested incorporating such wastes about 1 wt% in bitumen while another effort explored that blending of such material with bitumen reduced the optimum binder content (OBC). But the reasons behind such reduced OBC remain unexplored with its dynamic Young’s modulus (E) which is very much essential to demonstrate the struc-
tural integrity of the bituminous mix augment with cited modifier. Therefore, this investigation is objected to explore the hydrocarbon (H-C) branch propagation and presence of carbonyl acid in PC modified bitumen by Fourier transform infrared (FTIR) microscopic test. However such test describes chemical changes of the binder for which structural integrity of the mix accelerated with increasing the dosage of cited modifier and thus OBC has been reduced. Again visualization of those modified blends have been experienced in micro-level by optical micrographs to show the homogeneous dispersion for different blending percentage of the cited modifier. Finally ‘E’ values of the bituminous mixes enriched with such modified blends have been experienced by ultrasonic pulse velocity (UPV) apparatus in 125 volt and 54 kHz frequency as found in literature.

II. Materials and methods

A. Materials

VG 30 grade bitumen has been selected as the base bitumen supplied by the Sodhpur hot mix plant and physical properties of such material is affixed in the Table 1.

| Properties                     | Actual value | Desirable value | Method of test Ref. to |
|--------------------------------|--------------|-----------------|------------------------|
| Specific gravity               | 1.050        | 1.05            | IS 1202 : 1978         |
| Penetration (100 g, 5 s at 25°C) | 68.00        | 60              | IS 1202 : 1978         |
| Softening Point, °C (Ring and Ball Apparatus) | 45.00        | 45              | IS 1205 : 1978         |
| Ductility, cm                  | >100         | 75              | IS 1208 : 1978         |

Besides that, littered PC (Fig. 2) of 150 μm has been collected from the garbage of MSW and cleaning the same as per typical recycling plant and then such material is dried in the ambient temperature for few hours. Thereafter, such material has been shreded in to tinny pieces of 1 cm×1 cm size for blend in cited base bitumen.

Fig. 1. Littered plastic cup.

However some properties of such waste has been affixed in Table 2.

| Properties                     | Value |
|--------------------------------|-------|
| Melting temperature (°C)       | 100–120 |
| Decomposition temperature (°C) | 336–366 |
| Specific gravity               | 0.9005 |
| Crystalline particles (%)      | 65    |
| Glass transition temperature (°C) | –25   |

B. Preparation of sample

First of all preheated (180°C) VG 30 bitumen has been blended with shredded PC in an amount of 0.5, 1, 2, 3, 4 and 4.5% by weight of bitumen individually. However such blending has been done with laboratory stirrer in 3500 rpm at 180 to 200°C during 45 min. After that mixing, some portion of the blend has been stored for chemical as well as morphological characterization and residual bituminous blend has been used to prepare dense bituminous macadam mix as per guide line stipulated in Ministry of Road Transport and Highways (MORTH, 2013).

Dense Bituminous Macadam (DBM) grade-2 of basaltic aggregate has been selected as a skeleton of the cited bituminous mix. However gradation of such mix has been affixed in Fig. 2.
However aggregate properties have been illustrated in Table 3.

**Table 3. Physical properties of aggregates**

| Property                      | Desired value | Actual value | Method referred |
|-------------------------------|---------------|--------------|-----------------|
| Coarse aggregate (C.A.)       |               |              |                 |
| Los Angeles Abrasion (%)      | Max. 35%      | 19.35        | IS : 2386 Part IV |
| Aggregate Impact Value (%)    | Max. 27%      | 17.89        | IS : 2386 Part IV |
| Specific gravity of C.A.      | Min. 2.7      | 2.84         | IS : 2386 Part II |
| Water absorption (%)          | Max. 2%       | 0.88         | IS : 2386 Part II |
| Fine aggregate (F.A.)         |               |              |                 |
| Specific gravity of F.A.      | –             | 2.78         | IS : 2386 Part II |
| Water absorption (%)          | –             | 1.62         | IS : 2386 Part II |
| Filler (OPC 43)               |               |              |                 |
| Specific gravity              | 1.05          | 1.05         | IS : 2386 Part II |

Moreover 126 nos. samples have been prepared for getting the optimum binder contents (OBCs) of the cited PMB mixed Marshall samples. After that, those OBC has been used to make Marshall samples to get ‘E’ with the help of UPV apparatus.

**C. Experimental studies**

**C.1. Fourier Transform Infrared (FTIR) analysis of plastic cup modified bitumen**

Place a small drop of the modified bitumen on one of the KBr plates. Thereafter the second plate on top to make a quarter turn for obtaining a nice even film. Place the plates into the sample holder of FTIR instrument and run a spectrum in a range of 400 to 4500 cm\(^{-1}\) wave number. However from the obtained micrograph the peak in the range of 1300 to 1700 cm\(^{-1}\) wave number shows the presence of carbonyl acid and 2700 to 3300 cm\(^{-1}\) wave number indicates the H-C branch propagation. Moreover presence of less amount of carbonyl acid indicates the more adhesive property of the binder.

**C.2. Morphological analysis of modified bitumen by optical microscopic test**

A drop of hot modified bitumen is sandwiched between couple of microscopic slides and tapped with the stickers from both ends of that pair of slides. Then they were observed by an optical microscope having 20X magnification power and the image is captured by AxioVision 4.8 software. However even dispersion of the PC droplets in the bitumen medium indicates homogeneous bituminous blend.

**C.3. Determination of ‘E’ value by UPV test**

Aquatics P-wave has been passed through the Marshall sample to get the ultrasonic pulse velocity (V) displayed in the screen of Proceq 500+ apparatus. However to get the dynamic Young’s modulus (E) by the eq. (1), such velocity is the key parameter.

\[
E_{UPV} = V^2 \times \rho \times \frac{(1 + \nu) (1-2\nu)}{(1-\nu)}
\]  

(1)

where, ‘\(\nu\)’ is the Poisson’s ration of bituminous mix (0.35) whereas ‘\(\rho\)’ is the bulk specific gravity of the compacted Marshall sample as obtained in the Marshall mix design. However structural integrity of such sample has been obtained by plotting the graph where Marshall Quotient (M.Q., i.e. ratio of Marshall stability to the flow value) makes the abscissa and ordinate has been made with the ‘E’ value. However declined linear relationship of both the parameter indicates brittleness of material.
III. Results and discussion

A. Chemical analysis of plastic cup modified bitumen by FTIR micrograph

However, lesser peak between 1300 to 1700 cm\(^{-1}\) wave number in FTIR micrograph of the PC modified bitumen in Fig. 3 shows that, after incorporation of 1 wt% PC modifier to the base bitumen carboxyl acid is getting reduced as compared to the entire studied blend. Precisely incorporation of 0.5 and 1 wt% of plastic cup to the base bitumen absorbs the carboxyl acid from the bitumen while beyond that limit peak of H-C chain is getting prominent in a wave number 2700 to 3200 cm\(^{-1}\) for every incremental dosage of PC to the bitumen i.e. 2, 3, 4 and 4.5 wt% PC. This seems that, PC first of all absorbs all the carboxyl acid from the bitumen and makes it more adhesive by making it viscous. Thereafter, H-C chain of PC and bitumen attached together to form more stiff bitumen and at a certain limit the visco-elastic bitumen becomes brittle material. Hence at a certain limit (i.e. 1 wt%) PC acts as a good modifier to make significant PMB.

B. Morphological analysis of plastic cup modified bitumen by optical micrograph

Visualization of the PC droplet dispersion on the base bitumen media by the 20X optical micrograph is the strong evidence for compatibility check up of such droplet to the cited media as fabricated in Fig. 4. However, incremental dosages of PC up to 2 wt% in the 180ºC hot bitumen suitably compatible with the same with prominent dispersion. Moreover, even dispersion of such droplets indicates that up to 2 wt% PC in the base bitumen makes the blend homogeneous rather than other higher proportion i.e. 3, 4 and 4.5 wt%. Apart from that, as the PC dosage increases in the blend, bitumen becomes stiff only for the presence of swollen polymer strands as shown in Fig. 4F.
C. Evaluation of structural integrity of plastic cup modified bituminous mix

Marshall Quotient (M.Q.) is considered as the stiffness index of the bituminous mix throughout the globe. But in recent days, dynamic Young’s modulus (E) has been treated as the sole parameter to judge the flexibility of cited mix under the traffic loading condition. Therefore, this investigation tries to plot both the parameters in a graph to obtain a best structural integrity of bituminous mix. Again from the Fig. 5 it is observed that every increment of M.Q. drops the E value for PC modified bituminous mix. However as per Indian standard guideline the M.Q. for any modified bituminous mix in hot climate should lies between 2.5 to 5\(^1\). Therefore, from the Fig. 5 it has been observed that for the cited standard M.Q. value, the ‘E’ of the PC modified bituminous mix ranges in between 38000 to 32000 MPa for 0.5 to 1 wt% PC dosage. Whereas beyond such dosage limit, ‘E’ value frequently falls and such trend indicates less structural integrity in bituminous mix.

![Graphical relation between dynamic Young's modulus and Marshall Quotient of plastic cup modified bitumen.](image)

Fig. 5. Graphical relation between dynamic Young’s modulus and Marshall Quotient of plastic cup modified bitumen.

IV. Conclusion

Incorporation of PC from 0.5 to 4.5 wt% in the VG 30 grade bitumen has been characterize in this investigation to explore the reason of less consumption of bitumen content in the dense bituminous mix. However the findings of the investigation are –

FTIR micrograph of the PC modified bitumen shows that, after incorporation of 1 wt% PC modifier to the base bitumen, carbonyl acid is getting reduced as compared to the entire studied blend. This result indicates that in that percentage bitumen achieved significant adhesive property.

Incremental dosages of PC up to 2 wt% in the 180°C hot bitumen suitably compatible with the same with prominent dispersion. Moreover, even dispersion of such droplets in the optical micrograph indicate that up to 2 wt% PC in the base bitumen makes the blend homogeneous rather that the other higher proportion i.e. 3, 4 and 4.5 wt%.

Dynamic Young’s modulus (E) value has been obtained for standard M.Q. value of the PC modified bituminous mix ranges in between 38000 to 32000 MPa for 0.5 to 1 wt% PC dosage. Whereas beyond such dosage limit, ‘E’ value frequently falls and such trend indicates less structural integrity in bituminous mix has been obtained.

However abridging the above discussion in mind it is concluded that blending of 1 wt% PC to the base bitumen will gives the significant structural integrity due to reduced amount of carbonyl acid in the modified bitumen. However dynamic Young’s modulus value of the bituminous mix is ten times higher than the desirable value prescribed in Indian standards\(^2\). Therefore, reduction of such experimental value obtained by UPV method to the standard value will be treated as the future scope of work.

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