Feasibility study of low density polyethylene modified bituminous mix in DBM layer of flexible pavement

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Abstract. An efficient and adequate system of transportation is inevitable for the development of any country. A high traffic intensity in terms of overloaded commercial vehicle, introduction of new axle configuration, significant variations of daily and seasonal temperature of the pavement are significant factors contributing to early development of distress symptoms like ravelling, rutting, cracking, bleeding, shoving and pot holing of bituminous surfacing, which demand a proper strengthening of pavements. The early development of distress in the pavement with the conventional mixes revealed the need of design specification based on performance tests. To overcome such kind of distress, properties of bitumen and bituminous mixes can be improved to meet the requirement of pavement with the incorporation of certain modifiers. The present study evaluates the Low-Density polyethylene (waste milk pouches) modified bituminous mix properties corresponding to the optimum binder content by conducting different performance test. Experimental studies demonstrated that waste milk pouches (6% by weight of the binder) modified bituminous mix gives the best result in terms of stability and durability. Experimental results indicated that using the waste milk pouches in bitumen is not only a cost-effective mix but also a very good solution in terms of improving bitumen pavement mix properties. The present paper aims to highlight the change in properties by addition of modifiers in bitumen and develop a procedure to estimate the reliability of a particular mix design. By considering these aspects, statistically it has been proved that the bituminous mix obtained experimentally, is also reliable to be used in real life scenario.

1. Introduction
The Rapid industrialization aided by changing production-consumption pattern has emerged as the primary reason for sustainable impedance. Depletion of natural resources and generation of enormous waste from both industry and agricultural practices with subsequent inadequate disposal capacity are the major areas of concern throughout the world. Extensive research is being undertaken considering the re-use of these by-products as raw materials in different construction industry. Additional aspects converging to the recycle of these waste products is its significant utility in enhancing the performance of pavements as “Bitumen Modifiers”.

Mass production of plastic nowadays in different forms to accommodate societal demands has resulted in environmental pollution [1,2]. Plastic bags are made up of polyethylene (PE) mainly of chemical formula (C2H4)n. Re-use of these non-biodegradable products contributes to a sustainable solution for its efficient and effective disposal. Polyethylene has gained prominence as one of the most effective polymer additives increasing the service life of pavements [3]. A detailed review of polymer
consumption in day-to-day scenario focused on the abundance of milk pouches thereby incepting its incorporation in the present study as one of the modifiers in conjunction with RHA. This paper evaluates the reliability of the mix obtained from optimal percent of bitumen (when conventional binder is replaced by RHA) and varying percentages of plastic thereby promoting the usability of plastics in pavement construction to prevent premature failures.

Since the year 2000, the concept of using wastes as bitumen additives has gained reputation [4]. Mohammad et al. (2007) reported the addition of PE as the best alternative to conventional mix by achieving the incremental stability of the mix [5]. The advantage of stabilizing the stone mastic asphalt (SMA) mix in flexible pavements with shredded waste plastic was developed by Bindu et al. (2010) [6]. An analysis by Chen et al. (2002) portrayed that incorporating polymers into asphalt binders attenuated the major causes resulting in asphalt pavement failures [7]. Rice husk ash has been identified as another significant waste that can be used as filler material in hot mix asphalt instead of conventional filler yielding better Marshall Stability value as compared to conventional mix Sargin et al. (2013) [8]. Ahmad et al. (2017), Mishra et al. (2017) delineated a comprehensive study on how the addition of processed plastic in conventional bituminous mix contributed to increasing Marshall Characteristics [9, 10].

The objective of this present study is to establish the applicability and efficacy of the waste material containing LDPE in the binder course as a bitumen modifier. Considering their deterministic role in the performance enhancement of polymer-modified bituminous blends, the study was focused on the various performance analysis of the mix.

2. Materials and methodology

2.1. Materials

2.1.1. Plastic waste.

Plastic is integrated with our everyday life. Constant use of plastic not conforming to the specified standards has a detrimental effect on the environment. Hence, any use of plastic as a raw material in the construction process is gaining eminence to promote sustainability. In this study, waste plastic in the shredded form with size ranging between 2-8mm has been used for the present investigation. The source was waste milk pouches made of polyethylene that was abundantly available as household waste. The properties of which are listed below in table 1.

| Properties         | Description                        |
|--------------------|------------------------------------|
| Melting Point      | 130°C                              |
| Plastic Type       | Shredded thin plastic milk pouches  |
| Plastic material   | Low Density Polyethylene           |
| Density (gm/cm³)   | 0.94                               |

2.1.2. Aggregate.

Aggregates serve as the integral component of the pavement structure, bearing stresses due to wheel load as well as resist wear due to abrasive action of traffic. Proper choice of aggregates along with the correct proportioning affects the performance of pavements. The mineral aggregate used in this study were obtained from Pakur (Jharkhand, India) quarry. Representative samples have been examined in the laboratory and results are presented (table 2).
Table 2. Physical properties of aggregate.

| Properties                                      | Value | Specification |
|------------------------------------------------|-------|---------------|
| Impact Value                                   | 21    | Max 24%       |
| Crushing Value                                 | 17.5  | Max 30%       |
| Specific gravity (coarse aggregate)           | 2.57  | 2-3           |
| Specific gravity (fine aggregate)             | 2.68  | -             |
| Flakiness Index                                | 16.2  | Max 35%       |
| Elongation Index                               | 12.5  | Max 35%       |
| Los Angeles Abrasion Test                      | 18    | Max 30%       |
| Water Absorption test                          | 0.7   | Max 2%        |
| Stripping Value (%)                            | 2     | Max 5%        |

2.1.3. Rice husk ash.
Rice husk ash (RHA) is the by-product of the rice milling industry. Around 20 – 22% rice husk is produced in India as agricultural waste from paddy cultivation [11]. Roughly 25% of this accumulated husk becomes ash when burnt. It has an excellent pozzolanic property and is non-plastic in nature. In this study, RHA was collected from local rice mill of Burdwan district, West Bengal, India. The properties of which are detailed in table 3, along with their permissible limits as per IS 73 Specifications [12].

Table 3. Properties of rice husk ash.

| Properties         | Value  |
|--------------------|--------|
| Specific Gravity   | 1.95   |
| Plasticity Index   | Non-Plastic |
| Silica Content (%) | 90-95  |

2.1.4. Bitumen.
A hydrocarbon product solid at room temperature and highly viscous at a temperature above 100 degrees Celsius, bitumen acts as the major constituent in flexible pavement construction. For this study, 60/70 penetration grade bitumen has been selected. The physical properties of the same are given in table 3 along with their permissible limits as per IS specification.

Table 4. Physical properties of bitumen.

| Properties                                      | Value  | Specification |
|------------------------------------------------|--------|---------------|
| Penetration (at 25°C) (1/10th of mm)            | 64     | 50-70         |
| Ductility at 27°C, cm                           | 81     | >75           |
| Specific gravity at 27°C                        | 1.01   | >0.99         |
| Softening Point °C                              | 50     | 46-54         |
| Viscosity at 60°C, poise                        | 2482   | >2400         |
| Viscosity at 135°C, cSt                         | 371    | >350          |
| Flash Point Test °C                             | 306    | -             |
| Fire Point Test °C                              | 315    | -             |

2.2. Methodology
The mix has been designed as per the Marshall Method. Aggregates conforming to Grading-II for Dense Bituminous Macadam layer have been used for this research work. In this study, total tests were performed in three phases. In the first phase, Optimum Bitumen Content (OBC) was calculated by
varying the percentage of bitumen content using 2% Rice Husk ash (RHA) as a filler instead of conventional cement. In the second phase, the test specimens were prepared by varying the percentage of plastic content ranging from 2% to 8%. The plastic content increment was standardized as 2% by weight of OBC (obtained in the first phase) for determining the Marshall Parameters along with other relevant performance tests. From the results obtained on testing, the optimum plastic content was concluded. In the third phase, the bituminous mix was prepared with optimum waste plastic content (as obtained) by weight of OBC to determine the Reliability of the mix using statistical tools.

2.3. Experimental framework
2.3.1. Marshall stability test
The Marshall Test is used to design bituminous paving mixes by determining two important properties; stability and flexibility. Strength as obtained by Marshall Stability of the mix is defined as the maximum load sustained by a compacted mix at a standard test temperature of 60°C. The flexibility is measured in terms of flow value which may be regarded as its obverse property that determines the reversible response of the wearing course under the action of traffic loads. The optimum binder content (OBC) of the asphalt mixes were determined by evaluating the mixes with binder content from 4.75 wt.% to 5.75 wt.% at an increment of 0.25 wt.%, in accordance to the procedure of MS-2 guidelines [13].

2.3.2. Static Indirect Tensile Strength Test
This test is used to evaluate the resistance of bituminous mix against cracking and assess its sensitivity to moisture damage. To assess the susceptibility of the coating of aggregate and bitumen binder to moisture damage, tensile strength is determined according to ASTM D 4867 [14]. Tensile strength ratio (TSR) was thereby calculated as the ratio of average indirect tensile strength of conditioned specimens to the indirect tensile strength of un-conditioned specimens. The load at failure of respective specimens was recorded and the indirect tensile strength (ITS) was calculated from the following equation.

\[ \text{Indirect tensile strength (ITS)} = \frac{2P}{\pi dt} \]

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

2.3.3. Resilient Modulus Test
The repeated loading indirect tensile strength test was performed as per ASTM D4123 on compacted plastic waste modified bituminous mix for finding resilient modulus values at different temperatures [15]. The test was conducted by applying a compressive load in the form of haversine wave at 25°C, 35°C and 45°C for different Bituminous mixes. The samples were conditioned for 5 hours in an environmental chamber at a specific temperature and then subjected to a repeated loading pulse width of 100 ms, and pulse repletion of 100 ms.

2.3.4. Rut Depth Test
Wheel Tracking Device (WTD) was used to assess the rutting resistance of the bituminous concrete mixes. It is a destructive test and has a distinct feature of direct contact between the loaded wheel and rectangular test samples. The test was conducted on a rectangular sample having dimension 300x300x50 mm. In this test 20,000 passes were applied on the test sample at 45°C and the resulting rut depth was duly measured.

3. Reliability analysis of the optimum mix
Arriving at an absolute certainty regarding the performance of a particular mix is unfeasible. Moreover, relying on large safety factors is not only impractical but also cost-intensive. Reliability analysis, therefore, ensures an acceptable level of risk in mix design, thereby giving us a probability
regarding the satisfactory performance of the designed mix throughout its service period. It can be basically
precised as the guide for consistent performance of the subject considered.

Usually, an acceptable asphalt mix may be expressed by limits on
- Volumetric parameters
- Marshall flow
- Marshall Stability.

Hence, the overall reliability of a particular mix must take into account the probability that all the
limits are simultaneously satisfied. Although practically the parameters considered are statistically
dependent on each other yet for simplification, it has been assumed to be statistically independent for
the considered mix [16].

Hence the following expressions can be written as:

\[ R(D) = \text{probability (volumetric limits satisfied by D)} \times \text{probability (flow limits satisfied by D)} \times \text{probability (stability limits satisfied by D)} \]  

3.1 Probability analysis- governing limits

i. Volumetric limits are expressed in terms of limits on three parameters i.e. Void in Mineral
Aggregate (VMA), % Air Voids (VA) and % Voids Filled with Bitumen (VFB). Let us consider
a Cartesian space VMA x VA, theoretically the limits imparted represent a feasible area in this
space. If we review the limits directed by MORT&H for Dense Bituminous Macadam, it
provides the following criteria:
(a) Lower limit of VMA = 13% (b) limit of VA = 3% - 5% (c) limit of VFB = 65% -75%.

ii. Similarly for flow, the stipulated value of limits according to MORT&H specification is 2mm
and 4 mm respectively for DBM [17].

iii. Finally for the stability which is specified only by the lower bound value is 9 KN for DBM as
per MORT&H specification.

3.2 Determining the Probability Density Functions (PDF)

To develop the probability density function, corresponding to the obtained OBC 4.91% (by weight of
aggregates), the significant variation of different Marshall parameters have been studied. It can be
computed either by empirical or theoretical means. 30 Marshall Specimens were prepared at 4.91% OBC
and tested for VMA, VA, flow, and stability. The PDF can be obtained by the following steps:

(a) Develop a frequency diagram for data
(b) fit a theoretical PDF to the data
(c) use Statistical Hypothesis test to determine Goodness of Fit.

4. Result and Discussion

4.1 Marshall stability

Figure 1 represents the relationship between stability and percentage of plastic used in bituminous mix.
The stability value of the mix corresponding to 6% waste plastic modified mix provides the highest
value which is 40 percent higher than the control mix (consisting of no plastic). The result is attributed
to the increment of stiffness and flexibility of the modified mix by the incorporation of plastic. Beyond
6% plastic content, stability values slightly decrease thereafter with the increase of plastic additives. The
results also portray that the value of Retained Stability increases with the increase of plastic content up
to 6%, after which it decreases (figure 2).
Figure 1. Marshall stability vs plastic content.

Figure 2. Plastic content vs retained stability.

4.2 Static Indirect Tensile strength
The Indirect Tensile strength test was performed for both unconditioned and conditioned samples for the varying percentage of plastic content. Results identify that for both unconditioned and conditioned specimens, the highest value of strength is obtained corresponding to 6% plastic content with a Tensile Strength Ratio (TSR) of 93%.

| Plastic Content (%) | ITS (Unconditioned) (Kg/cm²) | ITS (conditioned) (Kg/cm²) | TSR (%) |
|---------------------|-----------------------------|----------------------------|---------|
| 0                   | 8.9                         | 7.3                        | 81.2    |
| 2                   | 7.6                         | 6.5                        | 85.6    |
| 4                   | 10.4                        | 9.3                        | 89.3    |
| 6                   | 14.3                        | 13.3                       | 93.5    |
| 8                   | 13.7                        | 12.9                       | 94.1    |

From figure 3, it is obvious that the use of a higher percentage of waste plastic in bituminous mix results in increased TSR which indicates that with an increase in plastic content, damage caused by ingress of water may be reduced to a large extent. Using 8% waste plastic as bitumen modifier provides the highest TSR value (94.1%).
4.3 Resilient Modulus Test

Figure 4 clearly shows the relationship of Resilient Modulus of the mix with varying plastic content with different test temperatures. Figure 3 displays the increment of stiffness modulus of asphalt mixes with the addition of plastic content and exhibited the highest modulus value for 6% plastic content followed by 8% for all test temperatures. The result signifies that the incorporation of plastic enhances the cohesion and stiffness nature of the mix.

4.4 Rut depth study

Rut depth has a direct influence on traffic safety and gives a measure of general road conditions. Rutting—a distress associated with pavements is usually expressed in terms of rut depth. The rutting resistance of asphalt mixes was expressed in terms of their rut depth values as stated in figure 5. From the figure it can be understood that rut depth is maximum for the control binder. Upon the addition of the plastic content, the rut depth decreases significantly. It can be observed that at 20,000 cycles, rut depth was ≈ 7.2 mm, 6.1 mm, 5.6 mm, 3.7 mm and 4.1 mm for the mixes prepared with 0 wt. %, 2 wt. %, 4 wt. %, 6 wt. % and 8 wt. % plastic content, respectively. The decrease in rut depth in mixes prepared using waste plastic can be credited to the increase in stiffness, cohesion and elasticity of the mix.
4.5 Reliability Analysis

4.5.1 Frequency Diagram and Fitting a Standard Probability Density Function

After extracting the data required from observation, the frequency diagram was obtained by plotting the frequencies corresponding to the intervals. The obtained data has been divided into finite intervals and thereafter the frequency of a particular variable calculated considering its repetition in the particular interval. A standard distribution or PDF represents the frequency diagram so obtained. The method of moments has been used to determine the parameters of the chosen PDF. Computing the mean and standard deviation of the observed data conceived the fitted normal distribution.

| Variable | Observed Value | Mean       | Standard Deviation | Fitted Distribution     |
|----------|----------------|------------|--------------------|-------------------------|
| Flow     |                | 3.34       | 0.8152             | N (3.34, 0.815)         |
| Stability|                | 22.6       | 6.772              | N (22.5, 6.772)         |
| VMA      |                | 14.73      | 0.7603             | N (14.73, 0.760)        |
| VA       |                | 4.39       | 0.8517             | N (4.39, 0.85)          |

4.5.2 Calculation of reliability

\[
\int \int \frac{1}{1.90} e^{-\frac{(m-14.73)^2}{1.76}} \times \frac{1}{1.98} e^{-\frac{(r-4.39)^2}{1.26}} \, dm \, da = 0.75 \tag{2}
\]

\[
\int \frac{4}{1.835} e^{-\frac{(r-3.3)^2}{1.08}} \, dq = 0.79 \tag{3}
\]

\[
\int \frac{2}{9.0} e^{-\frac{(s-22.6)^2}{80.07}} \, ds = 1.02 \tag{4}
\]

From equation (1) and the probabilities obtained as above, Reliability = 0.75 × 0.79 × 1.02 = 0.601.
So, from the current investigation, it is statistically proved that the proposed mix is quite (60\%) reliable for field application.

4.6 Testing for Goodness of Fit
In this current work, a statistical hypothesis test like Chi Square has been used to assess the goodness of the obtained fit. It helps in finding out whether there is any consequential difference between the predicted and observed frequencies for each of the considered variables (flow, stability, VMA, and VA) thereby ensuring minimal effect on practical implementation with the current error in the approximation.

5. Conclusions
Taking into consideration the experimental investigations conducted and the detailed study involved, the following conclusions can be inferred.
1. Rice husk ash can be used as a mineral filler in binder course as cement replacement. By mixing rice husk ash in aggregate and LDPE containing waste milk pouches in bitumen as a modifier, Marshall Properties of dense bituminous concrete portrays a significant improvement.
2. By mixing 6\% waste plastic as a modifier, retained stability and tensile strength ratio (TSR) value was highly improved as compared to bituminous mix consisting of only RHA. Results imply that there was an enhancement in the moisture sensitivity of the mix.
3. The values of Modulus of Resilient at 35°C and 45°C for 6\% plastic waste modified mix are respectively 72 \% and 53\% higher than the only RHA added control mix. The reason may be the production of a denser and stiffer mix due to a decrease in air voids. Therefore, use of the rice husk ash-plastic waste composite was responsible to increase the indirect tensile strength of the bituminous mix.
4. It was observed that among the varied percentage of modifiers, 6 \% waste composite reduced rutting in bituminous mix during wheel track testing by a considerable amount. So, it can be particularly concluded that 6\% plastic mix gives the best-suited result in terms of minimizing permanent deformation.
5. Using 2\% RHA and 6\% plastic in the bituminous mix, the increased percentage of reliability value obtained clearly indicated a better and stable pavement in the construction industry. Thereby, the current investigation provides a viable solution in terms of solid waste management focusing on environmental sustainability and presenting a stable and cost-effective pavement.

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