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A sustainable approach: Utilization of waste PVC in asphalting of roads

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HIGHLIGHTS

- PVC is a carcinogenic plastic, it is difficult to recycle its waste, and it is burden on environment.
- In this study PVC pipe waste has been used as a modifier in making bituminous product for paving application.
- The addition of PVC pipe waste to the bitumen enhances both the bituminous binder's and the bituminous mix's properties.
- Addition of waste PVC reduced the rutting values and increased the fatigue life of the bituminous mix.
- PVC pipe waste can be successfully used in paving applications.

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ABSTRACT

The most problematic plastic produced today is polyvinylchloride (PVC). For years throw-away products made of PVC have been a leading cause of dioxin pollution in incinerators and when burned in fires. In this study PVC pipe waste has been used as a modifier up to a level of 3% and 5% of bitumen in making bituminous product for paving application. PVC releases dioxins when burned; so it cannot be directly heated with aggregate at high temperature. PVC waste can be used safely only when it makes a homogeneous blend with bitumen at a temp of 160 °C. PVC is not compatible with bitumen; therefore to make a homogeneous blend, waste PVC was initially treated with a chemical modifier and then blended with bitumen. The visco-elastic properties of the bitumen-PVC blend were studied. Later the performance characteristics of bituminous mix made up of these modified binders were studied and compared with those of conventional bituminous mix. The results indicate that PVC pipe waste can be used successfully in road construction. Strength and stability of the mix increased after incorporation of PVC pipe waste, and also increased resistance to permanent deformation was observed.

1. Introduction

The most problematic plastic produced today is polyvinylchloride or PVC, commonly called vinyl. World production of PVC today is at more than 20 million tonnes per year – up from 3 million tonnes in 1965 – which corresponds to about one fifth of the total plastic production. For years throw-away products made of PVC have been a leading cause of dioxin in incinerators and when burned in fires [1]. As more PVC is being disposed of we are now seeing the first stages of an impending PVC waste mountain with no safe way to dispose of it and with little hope it will be recycled.

Considering life spans of about 30 years and more, a significant increase of PVC waste quantities is expected to start around 2010 [1]. The trouble is there is no safe way to deal with this inherently hazardous waste material. In India, the collection, transportation and disposal of solid waste are unscientific and chaotic. Uncontrolled dumping of wastes on outskirts of towns and cities has created overflowing landfills, which have serious environmental implications in terms of ground water pollution and contribute to global warming [2].

Use of this non-biodegradable (according to recent studies, plastics can stay as long as 4500 years on Earth) product is growing rapidly, and the problem is what to do with plastic-waste [3]. If a ban is put on the use of plastics on emotional grounds, the real cost would be much higher, the inconvenience much more, the chances of damage or contamination much greater, the risks to the family health and safety would increase, and, above all, the environmental burden would be manifold. Hence the question is not 'Plastics vs No Plastics' but it is more concerned with the judicious use and re-use of plastic-waste [4,5].

Bitumen has been known to be used as a binder for road construction. However the performance of these bituminous binders is questioned time and again, given that they are brittle and hard in cold environments and soft in hot environments. The steady increase in high traffic intensity in terms of commercial vehicles and the significant variation in daily and seasonal temperature has led

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to increased demand for improved road characteristics. Any improvement in the property of the binder is the need of the hour [6]. It has been recognised that the deficiencies of bitumen can be overcome by the addition of polymers for improving visco-elastic behavior besides maintaining its own advantages. The addition of polymers typically increases the stiffness of the bitumen and improves its temperature susceptibility [7]. Use of waste plastic in bitumen has revealed improved performance, stability, strength and fatigue life, reduction in overall rutting, and reduced low-temperature cracking of the bituminous surfacing [8]. Apart from solving the problem of waste disposal, addition of waste plastics in bituminous mix results in reduction in consumption of bitumen thereby resulting in overall cost reduction [9].

In this study we report the reuse of waste of PVC construction pipes in the modification of bitumen for paving applications. The reason for its selection is that after secondary recycling, the properties of PVC could not be achieved even by adding increased doses of various additives, thus becoming a burden to the environment. Also there is no safe way to dispose or recycle waste PVC. To achieve gainful and safe reuse of PVC waste, the approach of bitumen modification with waste PVC pipes was chosen. The visco-elastic properties of the modified bitumen and the mechanical properties of the bituminous mix produced by this modified bitumen are investigated and compared to the neat bitumen to find how best this PVC pipe waste can be used for paving applications.

2. Experimental procedure

2.1. Materials

Shredded PVC pipe waste (2–4 mm) materials were obtained from a local recycler. The 80/100 penetration grade paving bitumen from Mathura refinery of India was used. The physical properties of bitumen are described in Table 1. The mineral aggregate [coarse aggregate (13.2 mm and 6 mm), fine aggregates (stone dust, lime powder) was obtained from the local quarry and its physical properties were checked and were found confirming to the MoRTH (Ministry of Road Transport & Highways) specifications. The tests were done as per BIS (Bureau of Indian Standards) code IS 2386.

2.2. Preparation of blends

The waste PVC particles were thoroughly washed and dried at 60 °C. After washing, the waste PVC was treated with a chemical modifier for homogeneous dispersion into bitumen. Treated PVC waste material was then used to modify neat bitumen at two different percentages, 3% and 5% by wt of bitumen. Mixing was performed in laboratory using an arrangement of oven, fitted with a stirrer having a speed regulating system. The frequency of the stirrer was 2000 rpm for preparing the blends and the time taken was 2–3 h. The resultant blend was stored at room temperature for further work. The physical properties of bitumen with different percentages of waste PVC were tested as per BIS 15462 and are given in Table 2.

2.3. Viscosities of modified bituminous binders

The viscosity profiles of the 80/100 pen bitumen blended with 3% and 5 % of waste PVC were measured using Brookfield Rotational Viscometer. The viscosity of bitumen blends were measured at various test temperatures at a rotational speed of 20 RPM of the Brookfield spindle No. 27. The viscosities were measured at 90 °C, 100 °C, 120 °C, 135 °C and 150 °C to see the variation in the viscosities with respect to temperature (see Table 3).

Table 1
Properties of bitumen (80/100 pen).

Properties	Test method	Value	Specification IS 73:2006
Penetration (25 °C, 100 g, 5 s), 0.1 mm	IS 1203-1978	81	80–100
Softening point (ring and ball), °C	IS 1205-1978	48	>40
Ductility at 25 °C (5 cm/min)	IS 1208-1978	75+	>75
Specific gravity	IS 1202-1978	1	>0.99
Viscosity at 60 °C, poise	IS 1206-1978	976	>800
Viscosity at 135 °C, Cst	IS 1206-1978	270	>250

Table 2
Properties of 80/100 pen bitumen with different percentage of PVC content.

Properties	%PVC in bitumen 80/100 pen bitumen	
	3% PVC	5% PVC
Penetration at 25 °C, 100 g, 5 s. 1/10 mm	55	44
Softening point (°C)	55	58
Elastic recovery (%)	32	25
Viscosity, 150 °C, poise	4.30	5.0
Phase separation, difference in soft. Pt, R&B, °C (maximum allowed is 3)	1	2

Table 3
Viscosity values of neat and waste PVC modified 80/100 bitumen.

Absolute viscosity results		Viscosity (cp)	
Temperature	80/100 pen bitumen	3% PVC waste modified 80/100 bitumen	5% PVC waste modified 80/100 bitumen
90 °C	8450	12,625	31,580
100 °C	3915	6000	11,100
120 °C	1225	1825	2520
135 °C	620	880	1150
150 °C	285	430	500

2.4. Rheology of modified bituminous binders

The viscoelastic response of the modified bituminous binders was evaluated using a Dynamic Shear Rheometer with plate and plate geometry by measuring complex shear modulus and phase angle. Measurements were taken in the temperature range 50 °C–85 °C. The 25 mm steel plate was used, the gap width set was 1 mm, and all measurements were taken at a frequency of 10 radians/s. The DSR measures a specimen's complex shear modulus (G^*) and phase angle (δ). The complex shear modulus (G^*) can be considered the sample's total resistance to deformation when repeatedly sheared, while the phase angle (δ), is the lag between the applied shear stress and the resulting shear strain. The specified DSR oscillation rate of 10 radians/s (1.59 Hz) is meant to simulate the shearing action corresponding to a traffic speed of about 55 mph (90 km/h). G^* and δ are used as predictors of HMA rutting and fatigue cracking. Early in pavement life rutting is the main concern, while later in pavement life fatigue cracking becomes the major concern. While performing the test, the samples were denoted as:

Sample 1: 80/100pen + 3% PVC
Sample 2: 80/100pen
Sample 3: 80/100pen + 5% PVC

Figs. 1–3 shows the Viscoelastic behavior of PVC waste modified binders and the neat binder i.e. 80/100.

2.5. Design of bituminous concrete (BC) mix

The mix design was done as per Indian Road Congress (IRC) guidelines and Ministry of Road Transport & Highways (MoRTH, India) specification 'section 500-18'. The aggregates were blended to obtain the values of standard BC grading as specified by MoRTH.

Marshall Samples were made as per the MoRTH specification for BC mix, with 75 blows on each face. This bituminous mix prepared with 3% and 5% waste PVC modified bitumen was then tested for the mechanical properties and were compared with conventional unmodified bituminous mix.

2.6. Mechanical properties of PVC waste modified bituminous mixtures

2.6.1. Retained stability test

Retained stability is the measure of moisture induced striping in the mix and subsequent loss of stability due to weakened bond between aggregates and binder. The test was conducted on the Marshall machine with the normal Marshall samples. The stability was determined after placing the samples in water bath at 60 °C for half an hour and 24 h.

$$\text{Retained stability } (\%) = \frac{\text{Stability after 24 h in water bath at 60 °C}}{\text{Stability after 30 min in water bath at 60 °C}} \times 100 \qquad (1)$$

The results are shown in Fig. 4.

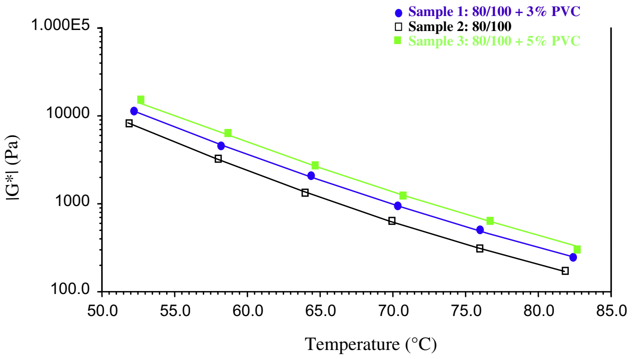

Fig. 1. Complex modulus of neat and waste PVC modified binders at different temperatures.

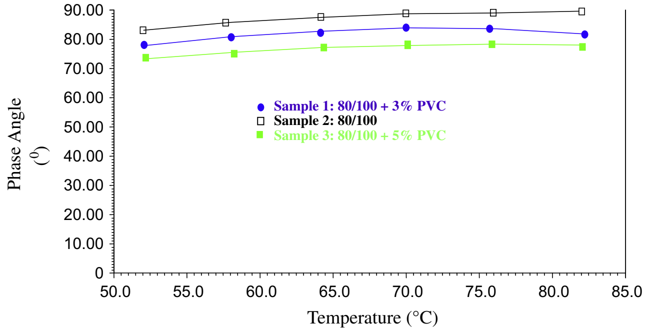

Fig. 2. Comparison of phase angle of neat and PVC waste modified binder.

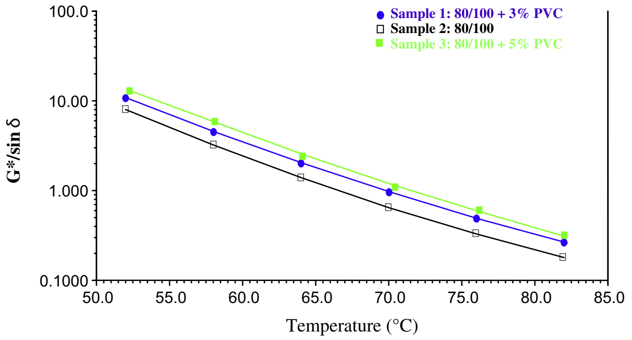

Fig. 3. Effect of addition of waste PVC on $G^*/\sin\delta$.

2.6.2. Indirect tensile strength (ITS) test

Indirect tensile strength test is significant to evaluate resistance of compacted bituminous mixture to cracking as well as sensitivity of mixture to moisture damage. To identify whether the coating of bitumen binder and aggregate is susceptible to moisture damage, Tensile Strength Ratio (TSR) is determined according to AASHTO T 283. TSR is the ratio of indirect tensile strength of conditioned specimens to the indirect tensile strength of unconditioned Marshall Specimens. The specimens (set of three specimen) were then placed in a water bath maintained at 60 °C for 24 h and then placed in an environmental chamber maintained at 25 °C for two hours. These conditioned specimens were tested for their tensile strength. The failure load was recorded and the indirect tensile strength, *St* was calculated using following equation

$$St = \frac{2P}{\pi t d} \qquad (2)$$

where, *P* is the load (kg), *d* is the diameter in cm of the specimen; *t* is the thickness of the specimen in cm. The TSR of specimen was computed by following formula:

$$\text{Tensile Strength Ratio (TSR)} = \frac{\text{ITS of Conditioned Specimen Set}}{\text{ITS of Unconditional Specimen Set}} \times 100 \qquad (3)$$

Results of tensile strength and TSR are plotted in Figs. 5 and 6.

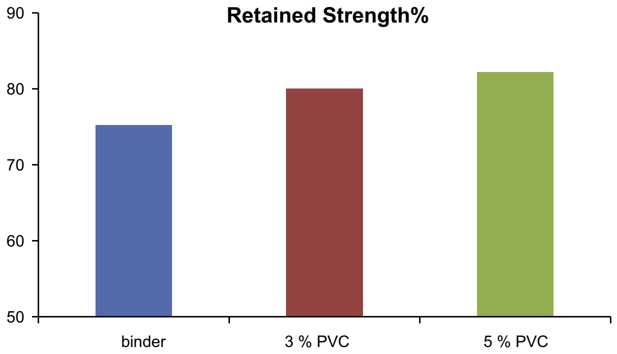

Fig. 4. Retained stability results.

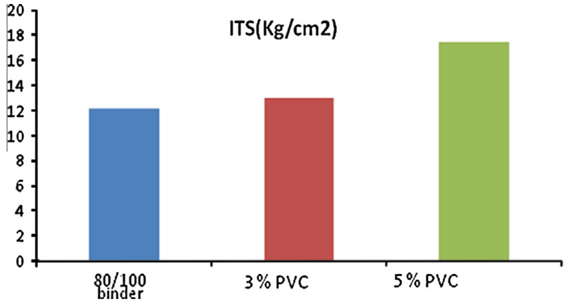

Fig. 5. Indirect tensile strength plots.

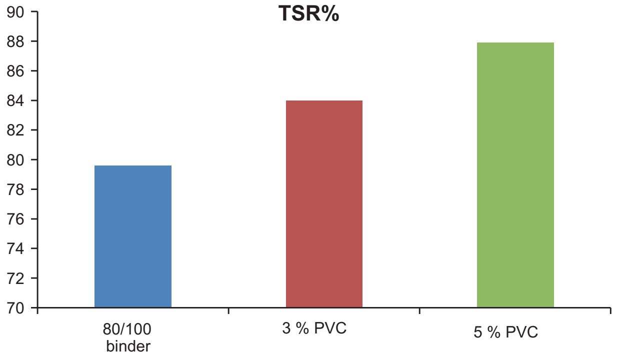

Fig. 6. Tensile strength results.

2.6.3. Rut depth studies by wheel tracking test

Rutting is an important parameter for design as well as for evaluation of performance of a bituminous mixture. To check the rutting resistance of the mixtures, tests were performed by Wheel Tracking Device (WTD), which is a destructive test and involves direct contact between the loaded wheel and the rectangular test specimens. The test was conducted on the prepared slab specimen of 300 × 150 × 50 mm at optimum binder content containing PVC pipe waste. The test was conducted at 50 °C and the resulting rut depth was measured. The data of rut depth of different BC mixtures are plotted in Fig. 7.

2.6.4. Beam fatigue tests

The purpose of the flexural beam fatigue tests is to measure the fatigue behavior of the mixture. A pavement can use the results from a beam fatigue test to provide an estimation of the number of wheel loads that can be carried before fatigue cracking appears. Each beam fatigue sample was prepared and tested in accordance with AASHTO Standard TP8. In this test repeated sinusoidal loading is applied. The load rate is fixed, but is normally 1–2 cycles per second. This produces a constant bending moment over the center of the beam. A load is often applied in the opposite direction, forcing the beam to return its original position to maintain the zero position during the test period. The deflection caused by the load is measured at the center of the beam.

The stress and strain at the outer fibers, and the stiffness modulus after about 50 load applications, are calculated using basic relationships for stress and strains in beams. The equation for calculation is as follows:

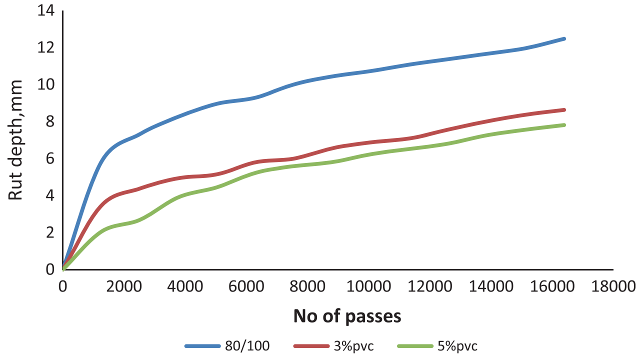

Fig. 7. Rut depths versus no. of passes.

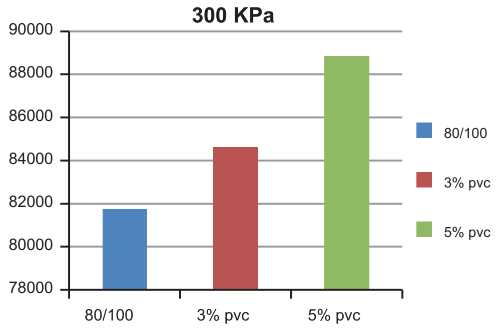

Fig. 8a. Fatigue life at 300 KPa stress value.

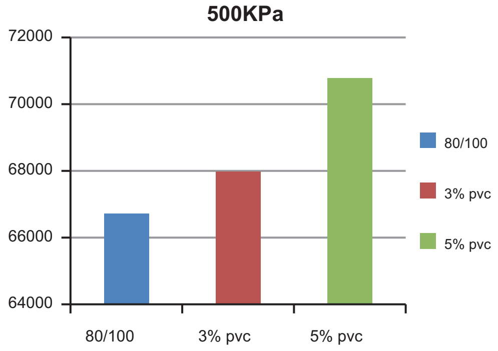

Fig. 8b. Fatigue life at 500 KPa stress value.

$$\sigma = 3aP/(bh^2) \tag{4}$$

$$\xi = 12hd/(3L^2 - 4a^2) \tag{5}$$

$$E_s = Pa(3L^2 - 4a^2)/(48Id) \tag{6}$$

where σ is the tensile stress in the outer fibers, N/mm^2; ξ is the tensile strain in the outer fiber, mm/mm; E_s is the flexural stiffness modulus N/mm^2; a is the distance between support and first applied load in mm; P is the total dynamic load with ½ applied at third points in N; h is the specimen height mm; L is the reaction span length in mm; I is the moment of inertia of specimen mm^4; and d is the dynamic deflection of beam at the center in mm.

The test can be conducted in the constant stress or constant strain mode of loading. In this study the test was done in constant stress mode. In the constant stress mode the applied load is repeated until failure occurs. In the constant stress mode of loading, the general equation for the plot of log of applied stress versus log of cycles to failure is:

$$N_f = K_1(1/(\sigma_t)n1 \tag{7}$$

Where N_f is the number of cycles to failure; and σ_t is the tensile stress in the outer fibers, N/mm2; K_1 and $n1$ = regression constants.

This test was carried at two different stress levels i.e. 300 KPa (intermediate traffic), 500 KPa (high traffic). The results of beam fatigue tests are given in Table 4 and shown in Fig. 8a and b.

3. Analysis of results

Results given in Table 1 indicate that the bitumen test values meet requirement of Indian Road Congress specifications (IRC 79, 2008). Results given in Table 2 shows that the addition of waste PVC increases the stiffness of the binder and hence gives the viscosity increase.

Fig. 1 shows almost linear relationship between complex modulus G^* and temperature. The slopes of the lines are similar for both (3% and 5%) waste PVC modified bitumen but are higher than the neat bitumen. The 5% waste PVC modified bitumen has the highest modulus in the temperature range as shown in the Fig. 1. Higher modulus at high temperature indicates better resistance to permanent deformation (rutting). Fig. 2 shows that the phase angle (δ) of waste pvc modified bitumen was lower than that of neat bitumen. The phase angle of 5% waste PVC modified bitumen was considerably lower than that of unmodified bitumen. Lower phase angle indicates lower viscous flow and higher elastic response. This indicates that polymer modified binders have high consistency and elasticity. Fig. 3 shows there was an increase in the $G^*/\sin\delta$ parameter of the original binder when the waste PVC was mixed. This indicates that the stiffness of the modified binder increases with the increase in the percentage of PVC and decreases with the increase in the temperature.

Results given in Fig. 4 indicate that retained stability of the mix increased with the incorporation of waste PVC. This indicates that the bond between the aggregate and the binder becomes stronger with the addition of waste PVC particles. When 3% waste PVC was added the retained stability of the mix increased up to a value of 80% from 75.5% of the neat binder and when 5% waste PVC was added the retained stability of the mix increased up to a value of 82.2%. The tensile strength ratio of the bituminous mixes deter-

Table 4
Beam fatigue test results.

Parameters	Stress300 kPa			Stress500 kPa		
	80/100 pen bitumen	3% PVC waste modified 80/100 bitumen	5% PVC waste modified 80/100 bitumen	80/100 pen bitumen	3% PVC waste modified 80/100 bitumen	5% PVC waste modified 80/100 bitumen
No. of cycles	81,750	84,635	88,835	66,720	67,985	70,780
Initial flexural stiffness (Mpa)	1309	1384	1410	1360	1375	1400
Maximum tensile strain (10^{-6})	509	405	440	612	525	570
Modulus of elasticity (Mpa)	638	788	912	832	848	860
Cumulative dissipated energy (MPa)	3.05	3.23	3.36	4.25	4.4	4.52

mines the moisture susceptibility of the mixes. TSR is widely accepted test to address damage caused by the ingress of moisture. The values of TSR of BC containing 3% and 5% waste PVC are recorded as 84% and 87.9% in comparison to the 79.6% of the control BC mix.

Rutting is a key factor for design as well as evaluation of the performance of bituminous concrete mixtures. It can be seen from Fig. 7 that observed rut depth values for 3% and 5% waste PVC modified mixes are much lower than that of control mix. Data plotted in Fig. 7 indicate that higher resistance to rutting is observed when waste PVC is added to the binder, indicating better resistance to permanent deformation. The same was also observed while studying the viscoelastic response of the waste PVC modified binder, where it showed higher values of complex modulus, G^* in case of modified binders. The increased rutting resistance due to the addition of waste PVC particles is because of better moisture resistance of the mix containing waste PVC and also due to the better strength of the mix achieved.

Data plotted in Figs. 8a and 8b show that the fatigue life of the bituminous mix improved after adding waste PVC into the bitumen.

4. Conclusions

Based on the results of the laboratory study the following conclusion can be drawn:

- PVC pipe waste can be successfully used in paving applications.
- The addition of PVC pipe waste to the bitumen enhances both the binder's as well as the mix's properties.
- Improved phase angle and complex modulus values were achieved after addition of waste PVC to the binder. It shows better resistance to the permanent deformation of the mix as compared to the mix prepared by neat 80/100 binder.
- Use of waste PVC led to the increase in values of indirect tensile strength to resist cracking.
- Addition of waste PVC reduced the rutting values of the bituminous mix to a greater extent and also increased the fatigue life of the bituminous mix.

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