Study of Effects of Waste PVC on the Properties of Bituminous Mixes

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ABSTRACT

Waste PVC that has been used previously as mineral water bottles, pipes, electrical fittings etc. are biologically non-degradable and posed an ominous environmental problem which led to severe environmental impact. But molten PVC has a binding property which can be reused with bitumen to reduce the cost of bituminous mix. At the same time the recycling of waste PVC save disposal sites and to reduce the amount of inert drawn from quarries, which often lead to environmental problems. This paper describes the investigation of the properties of bitumen mixed with PVC (2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20% by the weight of bitumen) at optimum bitumen content and to check the design criteria of bituminous mixes using this bitumen-PVC binder. The investigation concentrated on the test of strength properties of coarse aggregates and Marshall Design properties of bituminous mixes according to the test procedure specified by AASHTO. Some of the measured properties of bituminous mix with bitumen-PVC binder used in this study were within the acceptable recommended limits. On the basis of experimental results of this investigation, it is concluded that the dense graded bituminous mixes with bitumen containing PVC up to 10% can be used for bituminous pavement construction in warmer region from the stand point of stability, stiffness and voids characteristics.

Keywords: *Waste PVC, Bitumen-PVC binder, Bituminous mixes, Stiffness and void characteristics, Stability.*

1. INTRODUCTION

The amount of waste PVC is increasing day by day as the availability of the PVC is enormous. They either get mixed with Municipal Solid Waste or thrown over land area. This increased waste is rapidly filling the remaining sites for future landfills, causing a blown out in the cost of waste disposal. Their present disposal is either by land filling or by incineration. Both the processes have certain impact on the environment. To encounter this trend, considerable effort is being put into recycling waste, turning it into re-usable by products. Waste PVC derived from mineral water bottles, credit cards, toys, pipes and gutters, electrical fittings, furniture, folders and pens, medical disposables etc.

Waste PVC on heating molten at around 100°C to 260°C. Moreover, the molten PVC has a binding property. Hence, the molten PVC materials can be used as a binder and they can be mixed with binder like bitumen to enhance their binding property. This may be a good modifier for the bitumen, used for road construction.

Many investigations have found that the strength of the paving mixes can be enhanced by use of a binder formed by modifying available bitumen with certain additives like Sulphur and organic polymer. The modified polymers also improve temperature susceptibility and viscosity characteristics and help alleviating some common problems like bleeding of binder during peak summer temperature and stripping of aggregate in moisture prone areas.

The polymers used for modification of bitumen for paving purposes are generally styrene-butadiene-styrene, copolymer styrene-butadiene, rubber latex,

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ethylene vinyl acetate, copolymer PVC, polypropylene etc. Most of these polymers besides being costly are not available very commonly. That's why numerous works have been performed for modification of bitumen by using waste polymer which is used in the domestic purposes.

V. S. Punith and A. Veeraragavan describes the procedure for modification of 80/100-paving grade bitumen cement using reclaimed PVC (PE) derived from low-density PVC carry bags collected from domestic waste [1]. *Zahra Niloofar Kalantar, Abdelaziz Mahrez and Mohamed Rehan Karim* describes the properties of bituminous binder modified with waste PVC terephthalate. They also investigate the possibility of using PVC Terephthalate as polymer additives in Bituminous Mix [2]. *Sabina, Tabrez A Khan, Sangita, D K Sharma and B M Sharma* stated the performance evaluation of waste plastic/ polymer modified bituminous concrete mixes. They also describe the comparative performance of bituminous concrete mixes containing plastic/polymer (PP) (8% and 15% by wt. of bitumen) with conventional bituminous concrete mixes (prepared with 60/70 penetration grade bitumen) [3].

The prime objectives in this investigation were to find out the changing properties of bitumen after mixing of PVC and to get high strength bituminous mix. And also to check the bitumen-PVC binder is suitable or not for construction. This paper also represents the comparative performance of bitumen-PVC binder with conventional bituminous mix.

2. MATERIALS AND METHODS

2.1 Polyvinyl chloride (PVC)

Polyvinyl chloride (PVC) is a thermoplastic polymer. PVC is widely used in construction because it is cheap, durable, and easily worked. For the present study, waste PVC were collected from domestic waste, mineral water bottles, credit cards, toys, pipes and gutters, electrical fittings, furniture, folders and pens, medical disposables etc. and clean properly for the preparation of recycled PVC. This waste PVC then shredded in a shredding machine to form the size of the particle is 2-3 mm. The specific gravity of the waste PVC used in this study was 1.25.

2.2 Bituminous materials

The binder material used for this investigation was of 80-100 penetration grade bitumen and collected from Eastern Refinery, Bangladesh. Routine test as per AASHTO were performed on the bitumen sample and get the following properties: Specific gravity, 1.022; Penetration value (0.1mm), 84; Ductility value, 100^{+} cm; Solubility value, 99.85% and Flash & Fire point, 290°C/310°C.

2.3 Aggregates

In this investigation the crushed black stone were used as a coarse aggregate. Particles retained on 2.36 mm sieve were regarded as coarse aggregate (The Asphalt Institute, 1984) [4]. Fine aggregate portion of the aggregate blend (passes 2.36 mm and retained on 0.075 mm sieve) was taken from coarse sand. Non-plastic sand finer than 0.075 mm sieve was used as mineral filler [5]. Properties of mineral matter were determined according to the test procedure specified by AASHTO and the results are given in Table I.

Table- I
Properties of mineral matter

Properties	Coarse Aggregate	Fine Aggregate	Mineral Filler
Bulk specific gravity	2.79	2.46	…
Apparent specific gravity	2.86	2.66	2.63
Water absorption, %	1.45	3.10	…
Impact Test, %	17	…	…
Loss Angeles Abrasion , %	30	…	…

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2.4 *Gradation of aggregates*

To investigate the behavior of bituminous mixes with different aggregates, continuously graded bituminous macadam is essential. In the continuously graded bituminous macadam, the aggregate blend is designed to be evenly graded from coarse to fine so as to arrive at a dense mix with a controlled void content, hence producing a stable and durable paving [6]. The gradation of aggregates in bituminous mixes in the present investigation is given in Table II and Figure 1 [6].

Table-II

Gradation of aggregates in bituminous mixes

Sieve mm	% passing by wt		Cumulative retain %	Individual retain %	% of C.A, F.A & M.F	Individual wt. for 1200 gm
	Specification	Blend				
25.0	100	100	00	00		00
19.0	80-100	90	10	10		120
9.50	60-80	70	30	20	C.A = 58%	240
4.75	48-65	56	44	14		168
2.36	35-50	42	58	14		168
0.60	19-30	25	75	17		204
0.30	13-23	18	82	07	F.A = 38%	84
0.15	7-15	11	89	07		84
0.075	0-8	4	96	07		84
					M.F = 4%	48

C.A.= Coarse Aggregate, F.A.= Fine Aggregate & M.F.= Mineral Filler.

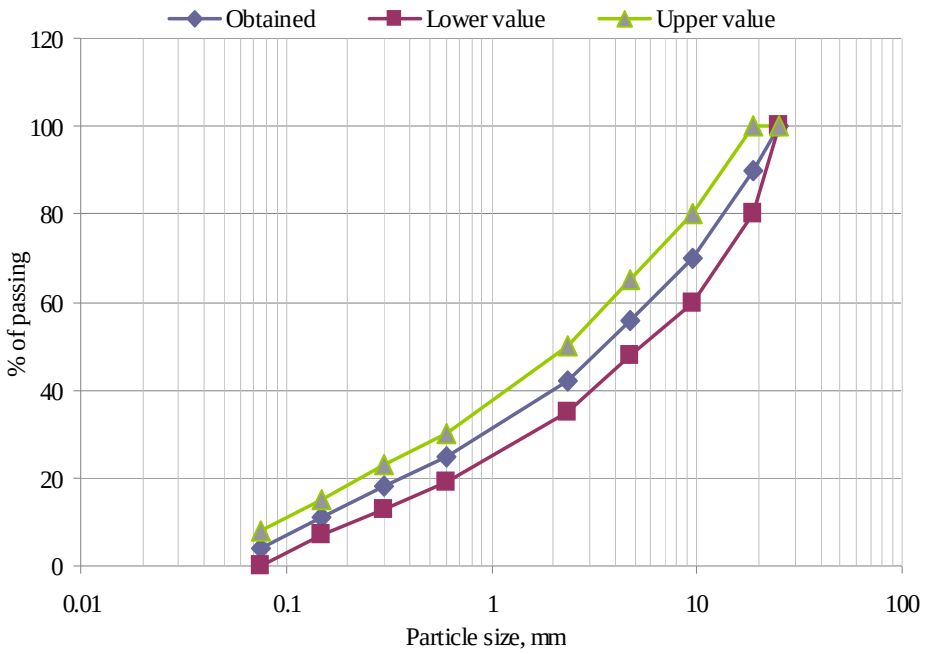

Fig. 1: Grain size distribution of aggregate gradation

2.5 Marshall test specimen

Approximately 1200g of aggregates and filler are taken and heated to a temperature of 170°C to 190°C. The compaction mould assembly and rammer are cleaned and kept pre-heated to a temperature of 100°C to 145°C. The bitumen is heated to a temperature of 121°C to 138°C and the required quantity of first trial % of bitumen is added to the heated aggregate and thoroughly mixed using a mechanical mixer. The mixing temperature may be around 154°C. The mix is placed in a mould and compacted by rammer, with 50 blows on either side. The compacting temperature may be about 138°C. The compacted specimen should have thickness of 63.5mm. The weight of aggregate taken may be suitably altered to obtain a thickness of 63.5±3.0mm [7].

2.6 Design of bituminous mixes

For determination of optimum bitumen content (OBC), Marshall Specimen was prepared by adding bitumen (4, 4.5, 5.0, 5.5 and 6.0% by weight of aggregate) into hot aggregate. Then, bulk density, Marshall Stability, flow and volumetric properties [air voids, voids filled with bitumen (VFB), and voids in mineral aggregates (VMA)] were determined for fresh bitumen. OBC for fresh bituminous mix was 5.4% (by the weight of aggregate). Further, Marshall Samples at OBC were cast using waste PVC (2.5, 5, 7.5, 10, 12.5, 15, 17.5 and 20% by weight of OBC) to determine bulk density and strength properties of the bitumen-PVC binder.

3. RESULTS AND DISCUSSION

3.1 Effects of waste PVC on the properties of bitumen

The molten PVC was homogeneously mixed with bitumen but the excess percentage of PVC causes the segregation of PVC from hot bitumen. Results shows in Figures 2, 4, 5 and 7 penetration value, flash & fire point, ductility value and solubility value decreases with the increase of PVC content on bitumen. The softening point value and specific gravity of the binder increases which shows in figures 3 and 6 due to the higher soften temperature and higher specific gravity of the waste PVC respectively. Lower penetration value indicates that the bitumen-PVC binder can be used in the warmer region.

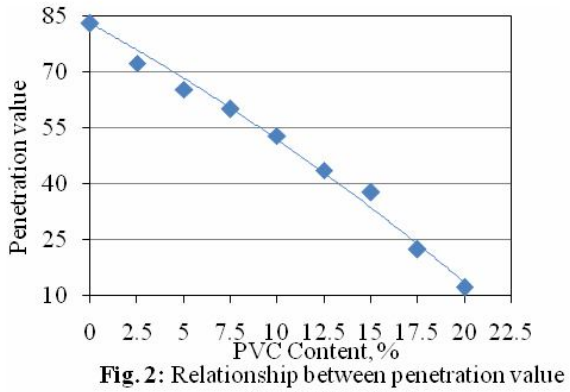

Fig. 2: Relationship between penetration value and PVC content

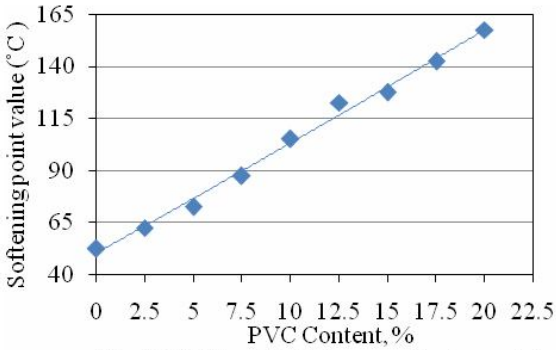

Fig. 3: Relationship between softening point value and PVC content

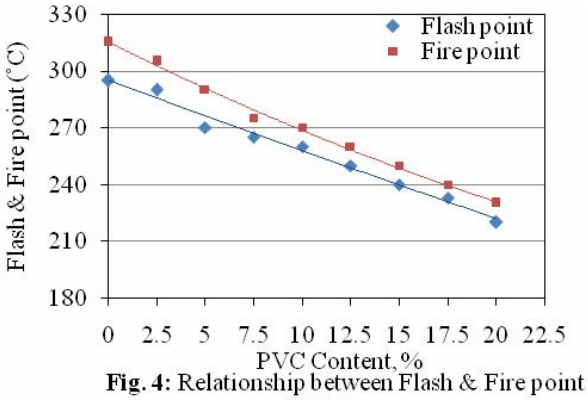

Fig. 4: Relationship between Flash & Fire point and PVC content

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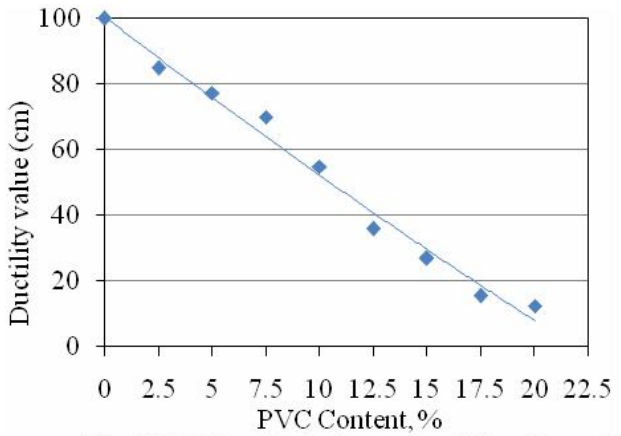

Fig. 5: Relationship between ductility value and PVC content

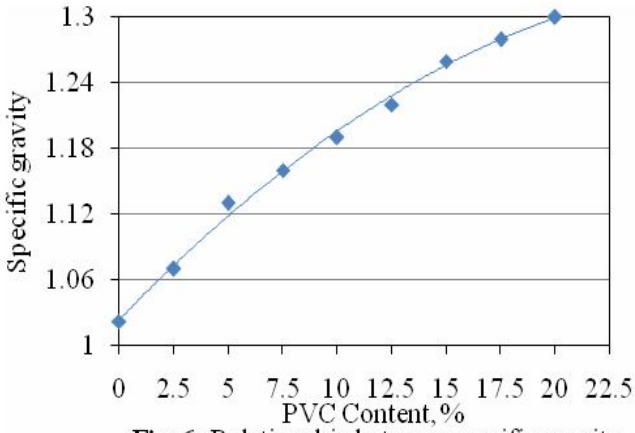

Fig. 6: Relationship between specific gravity and PVC content

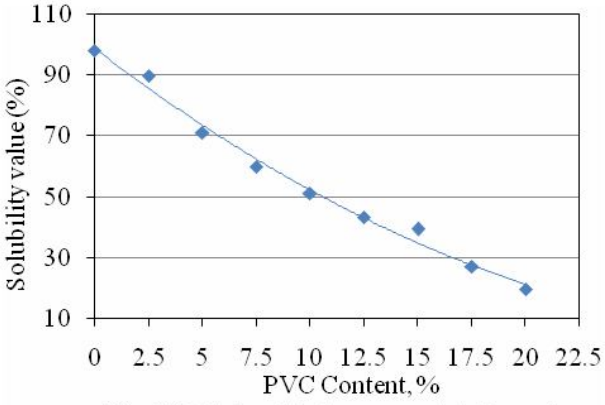

Fig. 7: Relationship between solubility value and PVC content

3.2 Effects of waste PVC on the bituminous mixes

Result shown in Figures 8 and 10 indicates that the unit wt. and stabilities of the compacted specimens increase initially with an increase in percentage of bitumen-PVC binder reach a maximum value and then decrease. With the increment of PVC on bitumen binder, the better compactions were done as a result the unit wt. and stability increased. For farther increment of PVC on bitumen, the waste PVC segregate from hot bitumen as a result unit wt. and stability decreased [5].

The void record of the mix with various percentage of PVC reported in Figure 9 shows that the percentage of voids in the total mix initially decreases with the increase in percentage of PVC on bitumen content. But for farther increase of bitumen-PVC binder, percentage of air voids increases. It is seen from Table III that the some percentage bitumen-PVC binder satisfies the limiting value (3 to5%) of percentage of air voids specified by The Asphalt Institute (1984) [4].

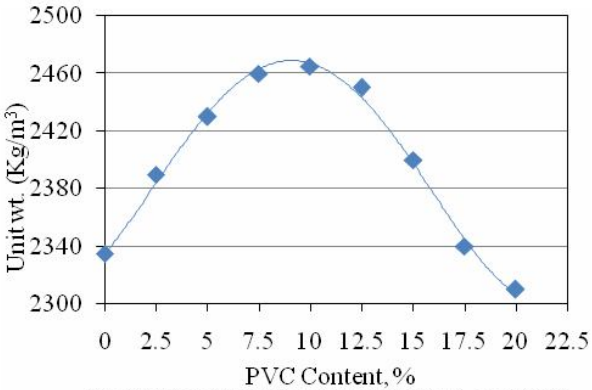

Fig. 8: Relationship between unit wt. and PVC content

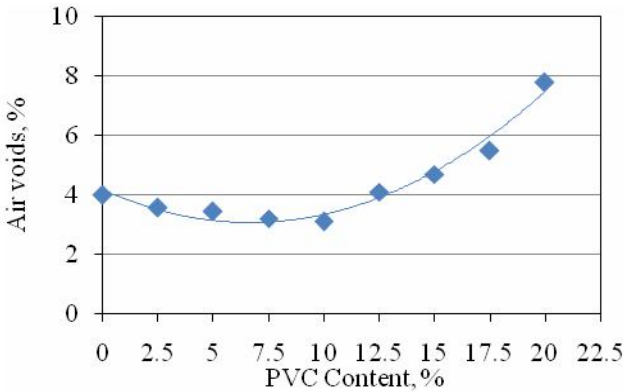

Fig. 9: Relationship between air voids and PVC content

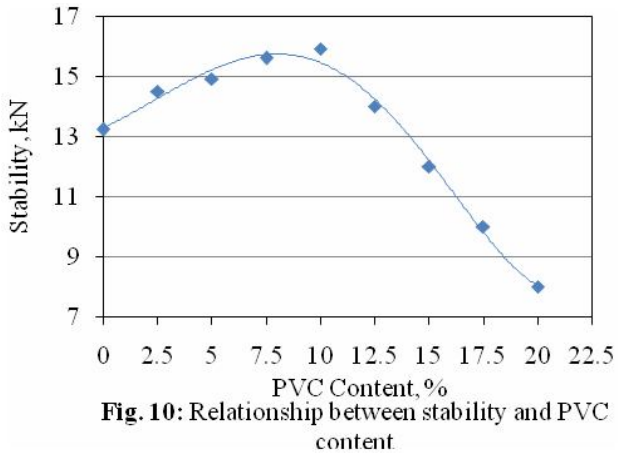

Fig. 10: Relationship between stability and PVC content

The flow value increases with the increase in PVC content with bitumen shows in Figure 11. For interpretation of Marshall Test results, Lees (1983) considered the stiffness (the ratio of stability to flow) of the mix which can be related to tyre pressure. In order to prevent permanent deformation of the mix under high stress, the Marshall stiffness should not be less than 2.1 kN/mm (120 lb/0.01inch) for the design tyre pressure of 100 psi. From Table III it is seen the Marshall stiffness are above required value 2.1 kN/mm up to 10% of PVC content on bitumen binder [8].

From the Figure 12, the void in mineral aggregate decreases with the increase in PVC content and after reaching a minimum value it increases with the increase in PVC content in bituminous mixes. On the other hand %VFB increases with the increase in PVC content and after a certain maximum value it decreases with the increase in PVC content in bituminous mixes shows in Figure 13.

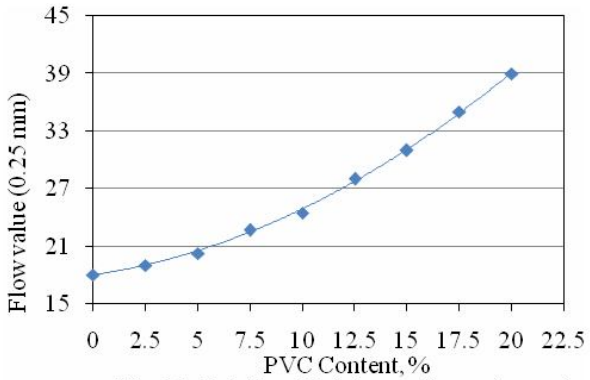

Fig. 11: Relationship between flow value and PVC content

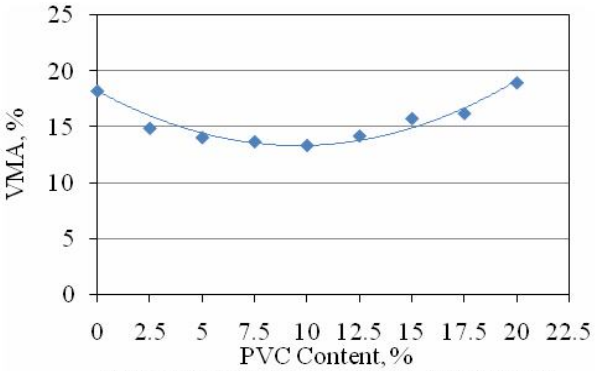

Fig. 12: Relationship between %VMA and PVC content

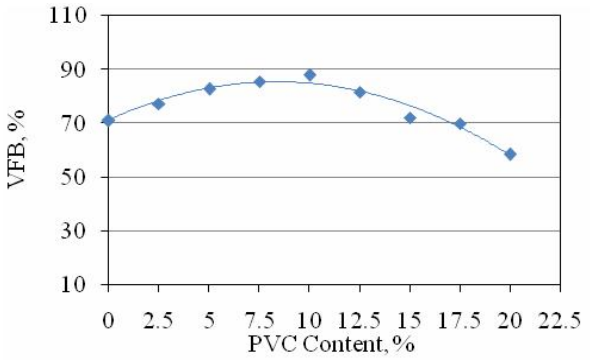

Fig. 13: Relationship between %VFB and PVC content

Table- III: Properties of bituminous mixes for various percentage of waste PVC

Properties	Fresh bituminous mix (5.4% OBC)	% of PVC content							
		2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0
Unit weight (Kg/m^3)	2335	2390	2430	2460	2465	2450	2400	2340	2310
% of air voids	3.99	3.58	3.44	3.21	3.10	4.10	4.70	5.50	7.80
Stability (kN)	13.22	14.50	14.90	15.60	15.90	14	12	10	8
Flow value (0.25mm)	18	19	20.30	22.70	24.50	28	31	35	39
%VMA	18.25	14.88	14.04	13.66	13.32	14.18	15.76	16.21	19
%VFB	71.12	77.34	82.77	85.46	87.96	81.79	72.25	70.01	58.48
Marshall stiffness (kN/mm)	2.94	3.05	2.94	2.75	2.60	2	1.55	1.14	0.82

4. CONCLUSIONS

On the basis of experimental results of this investigation, the following conclusions are drawn:

- The scrap PVC available from domestic and other waste can be utilized to modify the bitumen to obtain high strength mixes and to get better adhesion properties of bitumen.
- The recommended proportion of the PVC modifier is up to 10% by the weight of bitumen content can be used for construction of road in hot climate where low penetration grade bitumen is used.

The result found in this study are encouraging, however, further investigation is required to investigate the application of current mix design methods for bituminous mixture containing waste PVC.

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