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Performance evaluation of bitumen modified by various types of waste plastics

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HIGHLIGHTS

- The effect of waste plastics (window, blinds and cable) was investigated.
- Waste plastics hardened the bitumen according to their own physical properties.
- 3% Window waste additive is determined as optimum content.

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ABSTRACT

This study investigates the performance of bitumen modified by three groups of waste plastics (window, blinds and cable wastes) based polyvinyl chloride (PVC). Ten modified with the modifier content 1%, 3%, 5% and pure bitumens were tested and characterized in accordance with the Superpave performance grading (PG) system. The experimental tests performed in the study were conventional tests, rotational viscosity (RV), dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests. The obtained results showed that the addition PVC window and blinds wastes in the amount of 1–3% improved performance of modified bitumens at high temperatures. Despite the advantages of window waste and blinds waste additives on modified bitumen performance at high temperatures, at low temperatures performance of bitumen was not affected by these modifiers. Only cable wastes in the amount of 5% improved performance of bitumen at low temperatures. Based on the results of this investigation it can be noted that optimum usage of the waste plastics as modifier in bitumen were determined as in the amount of 3% window wastes.

1. Introduction

The increase in world population has led to a parallel and gradual increase in the demand for transportation. Because highways provide access to nearly everywhere, they are still the most commonly used transportation systems in the world for both passenger and freight transportation [1]. However, the increasing demand for transportation also leads to the rapid deterioration of highway pavements. The main approach used for preventing the deterioration of pavements is improving the properties of materials used for constructing highways [2]. Bitumen is a construction material used as binder in flexible pavements. The behavior of bitumen varies depending on vehicle speed and temperature. At high speeds and low temperatures, bitumen behaves more like an elastic solid. Under such conditions, the most commonly occurring type of deterioration is thermal cracks. At low speeds and high temperatures, on the other hand, bitumen behaves rather like as a viscous liquid, in which case the most common type of deterioration is wheel tracking. At normal environmental conditions and average speed values, bitumen exhibits viscoelastic properties, in which case the most common type of deterioration is fatigue cracks.

Bitumen is generally used in a modified form to minimize the effects of increasing traffic loads and adverse weather conditions. These modifiers improve the properties of bitumen, and thus the properties of the hot-mix asphalts (HMA) used in flexible pavements [3]. Polymer-based additives are frequently used for the modification of bitumens, and there are numerous studies in the literature on this subject [4–6]. Due to the high costs of the polymer-based additives, the use of waste thermoplastics is currently being considered for bitumen modification.

Plastics are low-density (that is, light-weight), durable, formable and low-cost materials which, owning to their properties, are widely used in many areas, sectors and industries. There are

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seven types of plastics:PET (polyethylene terephthalate), HDPE (high-density polyethylene), PVC (polyvinyl chloride), LDPE (low-density polyethylene), PP (polypropylene), PS (polystyrene), other types of plastics .

Disposed plastics materials do not decay, corrode, or dissolve. For this reason, they can remain intact in nature for many years. This undesirable feature results in the formation of considerable environmental pollution. However, plastic is also a recyclable material. The recycling of plastics not only allows the effective use of increasingly diminishing natural resources, but also reduces the amount of wastes that need to be buried underground, thus minimizing environmental damage. The modification of bitumen with plastics-based additives would allow additive materials to be provided at very low costs, while also permitting the utilization of waste plastics in nature. There are numerous studies in the literature regarding the modification of bitumen with waste plastics materials [7–9]. Kumar and Garg [10] investigated rheology of waste plastics-fiber bitumen. They found that, the properties of bitumen such as penetration, softening point and ductility were improved with the addition of the waste fiber. Also the optimum ratio of the fiber was found to be 0.5% on the basis of PG (Performance Grade) 70 in this study. Costa et al. [11] modified bitumen with different plastics wastes, namely polyethylene (high density (HDPE and low density LDPE), ethylene-vinyl acetate (EVA), sytrene-butadiene-styrene (SBS), acrylonitrile–butadiene-styrene (ABS) and crumb rubber. They investigated the especially storage stability of modified bitumen. The experiential tests performed in the study were penetration, softening point, dynamic viscosity and storage stability. They found that, SBS, EVA, or alternatively HDPE have showed good performance according to storage stability.

As PVC – which is a type of plastics – is an economic and easily installed material, it has recently replaced wood and concrete as construction material in many areas of the building sector. More than 50% of all PVC in the world is currently being used in the construction sector. In the United States, building and construction applications account for an estimated 75% of all PVC consumption. In the European Union, 60% of PVC is used in building and construction applications, with an additional 25% in appliances, electronics, and furniture [12].

Due to its great tourism potential and the high number of immigrants it receives every year, Antalya (Turkey) is a touristic city in which extensive construction activities are conducted. These extensive construction activities result in the production of considerable amounts of construction material wastes, which in turn lead to considerable environmental pollution. For this reason, in this study it is aimed to use PVC based construction material wastes to modify bitumens and improve their properties. To this end, a plastics waste material recycling facility in Istanbul was visited in order to obtain information regarding the three types of PVC based construction materials which are most frequently disposed of as waste material. Officials at the facility informed that the most common PVC based wastes were PVC window, PVC blinds and cable; it was hence decided that these materials would be used for bitumen modification purposes. Although all three of these waste materials are PVC based, the methods used for their manufacture are slightly different, which results in different structural properties for each one. In order to obtain the raw material for PVC blinds, for instance, calcite is added to PVC, which makes PVC harder and more brittle. To obtain the raw material for cable, on the other hand, dope oil is added to PVC, which makes PVC more flexible and formable. Finally, in order to obtain the raw material for PVC window, titanium-dioxide or barium-sulfate is added to PVC, which increases its workability. Experimental studies were thus planned to determine how each waste material affected bitumen properties. Superpave tests are commonly performed in modified bitumen studies [13–15]. These tests allow the identification of the behavior of pure and aged binding materials under the effects of compression, laying, high temperatures and low temperatures. This study aims to investigate and compare effects of waste plastics (window, blinds and cable waste) based PVC on the rheologic properties of bitumen.

2. Experimental

2.1. Materials

The binders were prepared with a pure bitumen having 160/220 penetration grade. The pure bitumen was obtained from Turkish Petroleum Rafineries Corporation (TUPRAS). Table 1 gives a summary of the results of some tests performed on the pure bitumen.

In this study, the waste plastics to be used as modifiers in 3 groups of ground PVC window, PVC blinds and PVC cable were obtained from a recycling facility in Antalya in the powder form.

2.2. Preparation of samples

In this study, modifying process of the bitumen was basically formed in accordance with the Turkish Highway Construction Specifications. Each group of waste plastics in powder form was sieved through a No. 50 sieve in a laboratory, resulting in modifier material with the necessary fineness for the experimental studies For each group of waste material, samples were prepared by using the waste materials at 1%, 3%, and 5% of bitumen weight. After heating bitumen up to 160–165 °C in the oven, it was poured into the chamber of the mixer. Following this, the modifier was slowly added to the bitumen, which was then mixed in the mixer at 500 rpm speed for approximately 15 min, until the mixture temperature reached 180 °C. After reaching this temperature, the mixer speed was raised to 1300 rpm, and the mixing process was continued for another 60 min. After this process; the samples were poured into small containers, which were covered by using aluminum foil, and then stored for use in the study experiments.

The different binders were coded as follows:

- pure bitumen – "B";
- pure bitumen +1%PVC_{WW} – "B-1-PVC_{WW}";
- pure bitumen +3%PVC_{WW} – "B-3-PVC_{WW}";
- pure bitumen +5% PVC_{WW} – "B-5-PVC_{WW}";
- pure bitumen +1% PVC_{BW} – "B-1-PVC_{BW}";
- pure bitumen +3% PVC_{BW} – "B-3 PVC_{BW}";
- pure bitumen +5% PVC_{BW} – "B-5-PVC_{BW}";
- pure bitumen +1% PVC_{CW} – "B-1-PVC_{CW}";
- pure bitumen +3% PVC_{CW} – "B-3-PVC_{CW}";
- pure bitumen +5% PVC_{CW} – "B-5-PVC_{CW}".

2.3. Testing program

2.3.1. Conventional bitumen tests

The pure and modified bitumens were subjected to penetration and softening point tests. These two tests were applied to the original bitumen and to the aged bitumen that was aged in a rolling thin film oven test (RTFOT) device. The bitumen was aged in the RTFOT device for 85 min at 163 °C; this aging process was performed in order to identify certain short-term aging properties that might be observed during storage, transfer to the plant, mixing in the plant, transportation, spreading and compression. Furthermore, to determine the sensitivity of each group tests' sample against temperature, the penetration index value (PI) was calculated by using the penetration and softening point values. The following equation was used to calculate the PI values: [16].

$$PI = \frac{1952 - 500 \times \log(Pen_{25}) - 20 \times SP}{50 \times \log(Pen_{25}) - SP - 120} \quad (1)$$

where Pen_{25} is the penetration at 25 °C and SP is the softening point temperature of bitumen.

Table 1
Physical properties of the pure bitumen.

	Specification	Results	Specification limits
Penetration (25 °C; 0.1 mm)	ASTM D5	198.67	160–220
Softening point (°C)	ASTM D36	38.75	35–43
Penetration index (PI)	–	−0.64	–