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Original Research Article

Waste frying oil modified bitumen usage for sustainable hot mix asphalt pavement

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ABSTRACT

Asphalt concrete is composed primarily of aggregate and asphalt binder. By volume, a typical Hot Mix Asphalt (HMA) mixture is about 85% aggregate, 10% asphalt binder, and 5% air voids. Bitumen is very important as a binder material in asphalt concrete. However, the cost of the bitumen is relatively high. For this reason, highway professionals are looking for modifiers to decrease the bitumen content used in the asphalt pavement. In this study, waste frying oil (WFO) is used as a modifier to modify the bitumen. As a result, by adding WFO into the bitumen, optimum binder content of a mixture was decreased from 5.125% down to 4.575%. So that, roads constructed with WFO modified bitumen are sustainable because of decreasing the bitumen rate used in the mixture. In addition, softening point of the modified bitumen is decreased (up to 82%) while the penetration value is increased (up to 240%) by modifying the bitumen with WFO. The tensile strength ratios of the modified asphalt specimens are all above the minimum specification limit, 80%. Finally, required temperature for fast self-healing is decreased by modifying the bitumen with WFO. Specimens prepared with WFO modified bitumen are healed compared to the reference specimen.

1. Introduction

Bitumen is commonly used as a binder for hot mix asphalt (HMA). Despite the widespread use of bitumen as a binder, the cost is relatively high. The increase in the traffic volumes and traffic loads leads to the need for improving bitumen properties, especially rutting resistance and thermal cracking. Therefore, virgin polymers are used for many years to improving the mechanical properties of bitumen [1,2]. However, using virgin materials is not sustainable. Pavement professionals are looking for a new material to strengthen the pavement to achieve economic gains through thinner design.

Waste frying oil (WFO) is commonly used in the whole world in different areas. This is normal when it is thought that the vegetable oil consumption in 2008 for the whole world was near 10^8 tonnes [3]. This tremendous amount of WFO is eliminated by pouring into the kitchen sink which harms the

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waste water treatment plant. One another solution of eliminating the WFO is to spilling onto the ground. However, WFO is eco-toxic. So they damage the plants [4]. In addition to this elimination method, one another way to rid of the WFO is dumping into rivers illegally. So, using the WFO as a binder modifier would reduce the damage given to the environment.

There are some studies about mixing WFO into aged bitumen [5–9] where it is shown that aged bitumen gets rejuvenated. However, they are studied about rheological properties of the bitumen. So, using pure WFO modified bitumen into HMA pavement and determining the mixture properties such as indirect tensile strengths and tensile strength ratios are unexamined, and also the effect of mixing WFO into HMA to optimum binder content will be studied in this paper.

In this study, WFO has been collected and filtered to be free of residues. Filtered WFO is mixed with bitumen 25% by weight, at 160 °C for an hour by 4000 rpm blender. Obtained WFO modified bitumen was unable to use in any hot mix asphalt (HMA) mixture because of its fluid structure. So, WFO rates are decreased by 1%, 3%, and 5% by weight of bitumen in the same manner as 25% by weight. Except this, any intermediate rate was tried because 5% by weight mixed bitumen was also soft enough. The penetration and softening point tests have been performed on each obtained WFO modified bitumen rates. Optimum binder content and the aggregate gradation for each WFO modified bitumen have been obtained by using volumetric mix design procedure. Therefore, specimens have been compacted using Superpave Gyratory Compactor (SGC). Finally, six specimens have been prepared with optimum binder content and aggregate gradation for each WFO modified bitumen rates. All the specimens have been tested in accordance with ASSHTO T 283 test procedure. A major goal of this study is to reducing the amount of bitumen used in HMA to achieve economic gains with some minor goals; obtaining a sustainable pavement, decreasing the workability temperature of the bitumen, producing a pavement with a self-healing feature at low temperature.

This paper puts forth usability of waste frying oil as a binder modifier with a short introduction followed by used Materials and applied Methods. Obtained results have been given in Section 4. Inferences made from this study are listed in Section 5. So, a pretty new usage area of WFO has put forth. There are not almost any studies about the usage of WFO in the bitumen or HMA. As a result of this study, a sustainable road which has less bitumen (a petroleum product) and WFO (harmful waste for the environment) in it has been obtained.

2. Materials

2.1. Aggregate

Limestone ($CaCO_3$) aggregate with 12.5 mm nominal maximum aggregate size is used as mixture aggregate and the properties are given in Table 1. The nominal maximum size is selected as wearing course value. Aggregate grading curve for asphalt mixtures is selected inconvenience with aggregate gradation control points (Fig. 1) [10].

Table 1 – Properties of limestone ($CaCO_3$) aggregate used in the tests.

Sieve diameter	Property	Standard	Value
4.75–0.075 mm	Specific gravity (g/cm^3)	ASTM C 127-88	2.660
	Saturated specific gravity		2.652
	Water absorption (%)		0.130
25–4.75 mm	Specific gravity (g/cm^3)	ASTM C 128 88	2.750
	Saturated specific gravity		2.428
	Water absorption (%)		2.800
	Abrasion loss (%)	ASTM C 131	20.38

2.2. Binder

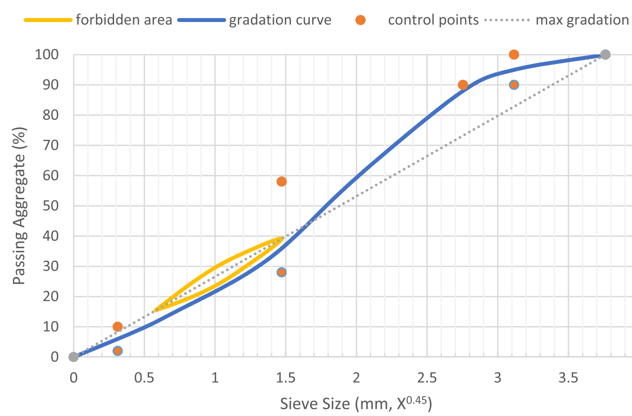

Fig. 1 – Gradation of the aggregates used in the study.

Standard tests are examined in order to determine properties of the non-modified binder. Test results are summarised in Table 2.

HMA samples are prepared with four different neat binder content (4.5%, 5%, 5.5% and 6%) to determine the amount of optimum binder content for mixtures prepared with non-modified bitumen. These samples are compacted using Superpave Gyratory Compactor (SGC). Test results are shown in Fig. 2.

As seen from Fig. 2, 4% air void is provided with 5.125% binder content. At the same time, 5.125% binder content ensures that the minimum voids in mineral aggregate (VMA) value is 14% for wearing course and limit values of voids filled with asphalt (VFA) is 65–75% interval [10]. According to the test results, as seen from Fig. 2, the optimum binder content is set as 5.125% by weight.

Table 2 – Non-modified binder characteristics.

Binder characteristic test	Average value	Standard
Penetration (25 °C)	50–70	ASTM D5
Flash point	180 °C	ASTM D92
Combustion point	230 °C	ASTM D92
Softening point	53.1 °C	ASTM D36
Ductility (5 cm/min)	>100 cm	ASTM D113
Specific Gravity (g/cm^3)	0.995	ASTM D70