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Performance properties of asphalt modified with reactive terpolymer

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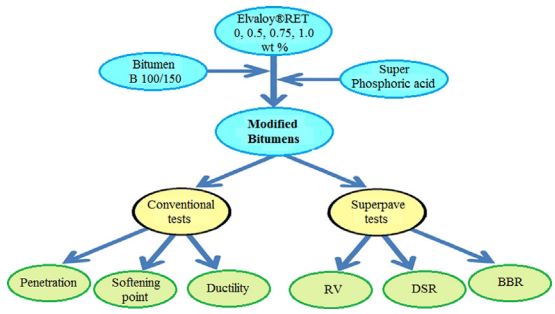
HIGHLIGHTS

- Effect of Elvaloy® RET on performance enhancement of asphalt was investigated.
- Addition of Elvaloy® RET increases stiffness of bitumen and decreases its temperature sensitivity.
- This additive is more convenient to be used in intermediate and very hot regions.
- Elvaloy® RET-1.0% is the most effective dosage to enhance rutting and fatigue resistance.
- Elvaloy® RET-0.5% is more convenient to decrease thermal cracking at low temperatures.

GRAPHICAL ABSTRACT



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ABSTRACT

This study aims to investigate the function and impact of the reactive terpolymer (Elvaloy® RET) in improving the performance properties of modified bitumens. To this end, four different percentages of Elvaloy® RET (0%, 0.5%, 0.75%, 1.0% by weight of bitumen) were mixed with B-100/150 grade bitumen. The physical properties of these binder samples were investigated using conventional tests such as penetration, softening point and ductility while their rheological properties were investigated using Superpave binder tests such as rotational viscosity, dynamic shear rheometer and bending beam rheometer test. The determination of high and low temperature performance grades of binder samples were supplied with the Superpave specification. The findings indicate that Elvaloy® RET-modified bitumens were less sensitive to temperature changes. Elvaloy® RET significantly improved the stiffness of bitumen. It also improved the resistance of bitumen against rutting and fatigue cracking, without causing a serious decrease in the resistance of bitumen against thermal cracking.

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1. Introduction

Asphalt binders, even though they are used in a limited proportion such as 5–7% by weight or 15% by volume in hot mix asphalts, are known to be significantly effective on the performance of the mixtures because of their physical and rheological properties [1–3].

In service temperatures, asphalt pavements undergo severe damages such as rutting, fatigue and thermal cracking under excessive traffic loads and adverse weather conditions. To overcome these defects, pure asphalts need to be modified chemically or physically to improve pavement performance. The aim of asphalt modification is to develop pavements with the aid of improved resistance to strains such as rutting, fatigue and thermal cracking [4–7]. Various researches have proved that asphalt modification improves its physical and rheological properties in accordance with the dose and property of the modifier [8,9].

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Nowadays, different modifiers such as natural, mineral, and industrial additives are commonly used to improve some properties of bitumens and mixtures. However, polymer-based additives are generally used to increase the resistance of bitumen and pavement against heat and traffic loads. Some research results indicate that the polymer additives increase the performance properties of bitumens at low, intermediate and high temperatures [3,10–12]. The two main types of polymer additives, elastomers and plastomers, have been utilized extensively for bitumen modification purposes. Plastomers (e.g., polyethylene [PE] and ethylene vinyl acetate [EVA]) are used in order to increase the elastic feature of the asphalt resistance with the aim of decreasing rutting in pavement at high service temperatures. On the other hand, elastomers reduce the viscous feature of asphalt binder. These additives (e.g. styrene-butadienestyrene [SBS]) and (styrene-butadiene rubber latexes [SBR]) are assumed to help reduce fatigue and thermal cracking strain of asphalt binder. However, under a certain load, elastomers deform faster than plastomers and recover elastically after resisting large strains [3,6,8,13–16].

In this study, Reactive Terpolymer (Elvaloy® RET or Elvaloy®4170), an elastomeric polymer, was used as a modifier to investigate its effect on physical and rheological properties of asphalt binders.

Reactive terpolymer is a polymer comprising functional groups capable of forming chemical bonds with some components of bitumen. This polymer produces a chemical reaction with asphalt which forms an inseparable compound by forming a network around the asphaltenes [16–21]. However, when chemical bonds are formed, in such a case, a completely useless polymer asphalt gel having no melting and dissolving ability can form [17,18,21]. Therefore, the amount of terpolymer that can be used in the asphalt modification must have an upper limit, in order to keep the network from forming below the chemical gel point [17,18,20]. Although this limit is about 2–2.5%, it can be lower than 1% by weight [18,21]. According to some investigators, it is thought that better results could be obtained with a polymer containing less reactive groups. In addition, it is also considered to be an economical disadvantage to use a higher polymer content. In studies, it has been indicated that it is not ideal that terpolymers are used alone as the modifiers, because they may have a weak effect on the performance of asphalt due to the risk of gel occurring [17–19,21]. When a terpolymer is mixed with asphalt, polyphosphoric acid (PPA) is usually added to the mixture in order to perform a catalyst function and accelerate the chemical reaction in mixture [16,17,19,22]. When PPA is used in the modification, it improves the properties of mixture such as rutting, aging and fatigue resistance, and reduces the amount of polymer needed in mixture [16–20,22].

According to previous studies, the use of reactive ethylene terpolymer in the bitumen modification resulted in an increase in softening point and viscosity of binders, and a decrease in ductility and penetration values [23–30]. In a study carried out by Witczak et al. [31] in which 0%, 1.5% and 2.0% Elvaloy® was used according to binder weight, the susceptibility of the modified mixtures to moisture damage was reduced significantly. In addition, the use of Elvaloy® led to a significant increase in the permanent deformation resistance of the mixtures. A previous study reported that the optimum ratio for Elvaloy additive was 1% in terms of low and high temperature and permanent deformation resistance. This was attributed to polymer-linked asphalt resulting from Elvaloy's chemical reaction with asphalt. It was also identified that 1% Elvaloy modified-bitumen showed the least loss of mass among the tested modified mixtures [30]. It is known that mass loss or aging of the asphalt is a result of the physical and chemical changes occurring during its mixing, compaction, and pavement life [7,19,32,33]. In many studies, it has been determined that Elvaloy has a very positive effect on aging resistance of modified bitumens [18,19,21,26,29]. This condition has been explained by the chemical reaction of carboxylic acid groups in asphaltene with Elvaloy [17,19,21,30]. Studies have shown that Elvaloy® RET gives a chemical reaction with asphalt and eliminates the problem of separation which can occur through storage and transportation as a result of this reaction [5,13,16,28,34]. Elvaloy® RET added to asphalt binders with different physical properties, gave a chemical reaction with bitumen, which clearly showed a 353% increase in the viscosities of the bitumens [28]. The results of another study have also showed improvement in rutting resistance of reactive terpolymer-modified asphalt [2]. Some studies have also showed that the addition of Elvaloy® RET to asphalt can cause a decrease in phase angle, while causing an increase in complex modulus. This shows a general improvement in rutting resistance of bitumens [1,31,34,16,17,35]. In a study which investigated the low temperature rheological properties of polymer modified bitumens, the cracking temperature of Elvaloy® RET was found to be higher [5]. However, the application of reactive terpolymer to bitumen tends to increase the high temperature grade without harming the low temperature grade significantly [29,30,35].

The purpose of this study was to better understand the performance characteristics of modified bitumens containing Elvaloy® RET through conventional and Superpave binder tests. Experiments such as penetration, softening point, ductility, rotational viscosity, dynamic shear rheometer and bending beam rheometer were performed to evaluate the engineering properties of modified bitumens.

2. Experimental

2.1. Materials

The pure bitumen with a B 100/150 penetration grade used in this study was obtained from Turkish Petroleum Refineries Corporation (TUPRAS). The physical properties of the pure bitumen are given in Table 1. The reactive terpolymer (Elvaloy® RET or Elvaloy® 4170) provided by DuPont Company was used as a modifier. Specifications of Elvaloy® RET is given in Table 2.

Elvaloy® RET, whose structure is given in Fig. 1, is an additive that gives a chemical reaction with asphalt, and the result of this reaction is as shown in Fig. 2.

This reaction increases the hardness and elasticity of the asphalt binder by forming a network around the asphaltenes [13,26,19].

Glycidyl methacrylate functional groups that are able to correlate with the carboxylic groups present in asphaltenes give rise to the reactivity in ethylene terpolymers as given in Fig. 3 [23,28,34].

2.2. Research plan

The research motivation has been to study the effect of Elvaloy® RET on the physical and rheological properties of bitumens. To this

Table 1
Physical properties of the pure bitumen.

Property	Standard	Specification limit	B 100/150
Penetration at 25 °C, 100 g, 5sec, 0.1 mm	ASTM D5	100–150	146.8
Softening point, °C	ASTM D36	39–47	45.45
Ductility at 25 °C, 5 cm per min, cm	ASTM D113	>100	124
Flash point, °C	ASTM D92	220	234
Ignition point, °C	ASTM D92	–	
Solubility in trichloroethylene, %	ASTM D2042	99	99.8
Specific gravity at 25 °C, gr/cm^3	ASTM D70	1.0–1.1	1.032
Penetration index (PI)	–		0.714

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