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Investigating the properties of crumb rubber modified bitumen using classic and SHRP testing methods

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ABSTRACT

Considerable effect of crumb rubber on improving the original bitumen properties along with environmental and economical advantages, encouraged using this additive as an effective modifier. In this research, due to lack of enough information about the effects of crumb rubber produced in Iran on 0/70 bitumen properties, extensive laboratory investigations have been carried out using classic and SHRP testing methods. The results of classic tests showed that adding crumb rubber reduced penetration, temperature susceptibility, ductility and fraass breaking point and increased the softening point, elastic recovery and vialit adhesion. Rheological properties of modified specimens were investigated with DSR in temperature sweep and frequency sweep and creep tests before and after aging in RTFO. Results indicated that there was an inflection point or inflection interval in G^*, $G^*/\sin\delta$ and $G^*{\cdot}\sin\delta$ diagrams. At higher temperatures and lower frequencies than the inflection point or inflection interval the aforementioned parameters increased by increasing the crumb rubber content and at lower temperatures and higher frequencies the reverse was true. Furthermore, increasing the crumb rubber content and aging in RTFO lead to reduce of creep and increase of viscosity quantity.

1. Introduction

Conventional bituminous materials have been used satisfactorily in most highway pavement and airfield runway applications. However, during the last decade increase in axle loads, heavy traffic, severe climatic conditions and construction failures led to a need to enhance the properties of the original bitumen. Environmental factors such as temperature, air, and water can have a profound effect on durability of asphalts. The ideal bitumen should be strong enough, at high temperatures, to withstand rutting or permanent deformation, and soft enough to avoid excessive thermal stresses, at low pavement temperatures, and fatigue, at moderate temperatures.

Properties of bitumens depend on the nature of the crude oil and on the refinery processes employed. However, the performance of bitumen is questioned, given that they are brittle and hard in cold weather and soft in hot environments.

These deficiencies of bitumen can be overcome by addition of polymers, which is known to endow bitumen improved viscoelastic behavior [1,2]. Blends of bitumen with polymers form multiphase systems. Such systems contain a phase rich in polymer, a phase rich in asphaltenes which not adsorbed by the polymer, and a phase formed by maltenes [3,4]. For a polymer to be effective in road applications, it should blend with the bitumen and improve its resistance (to rutting, abrasion, cracking, fatigue, stripping, bleeding, aging, etc.) at medium and high temperatures without making the modified bitumen too viscous at mixing temperatures or too brittle at low temperatures [5,6]. The effect of polymer modification on the linear rheology, depends on polymer nature and concentration, and testing temperature [7].

From an environmental and economic standpoint, use of ground tire rubber as a bitumen-modifying agent may contribute to solving a waste disposal problem and to improving the quality of road pavements.

In spite of several researches conducted in the field of CR modified bitumens, due to lack of enough knowledge in Iran, the main objective of this research was to investigate the effects of CR produced in Iran on the physical and rheological properties of 60/70 bitumen. In this regard, the following objectives were supposed:

1. Effect of CR on the basic rheological characteristics of studied bitumen such as penetration, adhesion, and elastic properties.
2. Investigating the temperature susceptibility of CR modified bitumen.

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3. Effect of CR on stiffness and cracking potential of the original bitumen using classic and Strategic highway research program (SHRP) testing methods.
4. Comparison between the results of classic and SHRP testing methods and investigating the correlation between results.

2. Crumb rubber–bitumen interaction

It has been established that the interaction between crumb rubber (CR) and bitumen is a physical one in which the CR, through diffusion, absorbs a portion of the aromatic fraction of the bitumen resulting in swelling of the CR particles [8]. The effective real particle size would be temperature dependent [9]. The interface of CR elastomer was clear and had many scattered slotted holes before blending, whereas, after blending the interface turned out to be indistinct, and the slotted holes will be disappeared [10]. Reduction in the oily fraction of the bitumen results in an increase in the CR–bitumen viscosity [8]. In order to prepare enough workability and controlling the amount of viscosity it may be needed to add oily components (e.g. aromatics or naphthenic oils) which will soften the bitumen.

There are several factors that affect the CR–bitumen interaction. On the part of the bitumen, the interaction depends on the amount of aromatic fraction, temperature, and viscosity. The properties of CR that can affect the interaction include production method (ambient or cryogenic grinding), particle size, specific surface area, and chemical composition (i.e., amount of natural rubber) [11]. Throughout the years, it has been reported that the specific surface area of CR is the most important physical property of CR which influence the interaction. This was found through viscosity measurement in CR modified bitumens (CRMB) [8].

Reduction in the oily fraction of the binder results in an increase in the CRMB viscosity. The reaction is generally considered completed when the viscosity of the blend becomes relatively constant. Rubber may be disintegrated, dissolved and/or reduced in molecular size, due to devulcanization and depolymerization processes [9]. This phenomenon will reduce the viscosity of CRMB.

Several research studies were conducted about the effect of CR particles size. Results of a study revealed that the CR with the maximum size of 0.15 mm exhibited the best effect on the dense-graded mixture whereas the 0.60 mm CR exhibited the best effect on the open-graded mixture of porous asphalt [12]. Furthermore, the increase of rubber size, regardless of rubber type, reduced the resilient modulus values but extended the fatigue life of the modified mixtures [13]. About the effects of CR type, research results indicated that the CR modified bitumens, containing ambient rubber, resulted in higher interaction effect and particle effect values than the CR modified bitumens made with cryogenic rubber [14,15]. This is due to the increased surface area and irregular shape of the ambient CR [13].

3. Experimental design

Two types of bitumens consist of 60/70 and vacuum bottom (VB) bitumens were used in this research. 60/70 bitumen has the maximum application in most regions in Iran. VB bitumen contains about 97% maltene and was used to supply the maltene phase needed for swelling of crumb rubber. The physical properties of 60/70, VB and base (included 80% 60/70 bitumen and 20% VB bitumen) bitumens have been presented in Table 1. The crumb rubber (CR) was prepared using type kt-m1 reclaimed tire rubber which was produced with ambient technique from Yazd Tire Company. The nominal size of CR particles was (0–1) millimeter.

The amounts of additives by total weight of modified bitumen have been presented in Table 2. According to this table, 12 compositions of bitumen and CR were prepared. Reference specimens which contained no CR were produced by mixing 80% of 60/70 bitumen with 20% VB bitumen with mixing condition similar to CRMB. The amount of CR for other specimens was between 6% and 26%. VB bitumen content for all specimens was equal to 20%. Therefore, by increasing the CR content, the amount of 60/70 bitumen reduced. As presented in Table 2, “s” and “rs” indicate the reference specimens before and after aging in RTFO, respectively. Aged specimens were conditioned in RTFO device for 85 min at 163 °C.

Table 1
Properties of 60/70, VB and base bitumen.

Property	60/70	VB	Base[a]
Penetration (0.1 mm)	64.7	257.0	75.7
Softening point (°C)	50.6	38.5	45.5
Ductility (cm)	>100.0	87.9	–
Elastic recovery (%)	17.0	14.0	14.5

[a] Admixture of 60/70 and VB.

Table 2
Composition of studied specimens.

Specimen name	Before RTFO	s	m6[a]	m8	m10	m12	m14	m16	m18	m20	m22	m24	m26
	After RTFO	rs[b]	–	–	r10	–	–	–	r18	–	–	–	r26
CR content (% by total weight)		0	6	8	10	12	14	16	18	20	22	24	26
60/70 content (% by total weight)		80	74	72	70	68	66	64	62	60	58	56	54
VB content (% by total weight)		20	20	20	20	20	20	20	20	20	20	20	20

[a] Numbers specify the CR content of each specimen.
[b] Conditioning in RTFO performed only for reference and specimens containing 10%, 18% & 26% CR content.

Table 3
Results of classic tests.

Specimen	Penetration (0.1 mm)	Softening point (°C)	Elastic recovery (%)	Ductility (cm)	Penetration index	Vialit adhesion (%)	Fraass breaking point (°C)
s	70.7	47.0	15	70.0	−1.16	70	−11
m6	67.4	50.9	24	–	−0.24	70	−8
m8	65.1	51.9	30	–	−0.07	72	−9
m10	62.4	53.5	36	–	0.13	76	−12
m12	59.8	54.2	38	17.5	0.24	80	−17
m14	58.5	54.8	40	–	0.32	80	−21
m16	57.3	55.7	42	–	0.47	86	−24
m18	55.7	57.0	45	–	0.68	90	−28
m20	54.0	58.4	50	14.3	0.90	96	−33
m22	52.1	60.5	56	–	1.23	96	−35
m24	49.6	63.1	62	–	1.61	96	−39
m26	47.7	65.7	70	12.7	1.98	98	−42