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Effect of wax on basic and rheological properties of bitumen with similar Penetration-grades

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Abstract

This paper presents the results of a study on the wax content, the basic and rheological properties of seven unmodified bitumens with Penetration-grades 60–70 and the effect of wax on these bitumens. Among the bitumens, one (currently used in Hong Kong) was supplied by a manufacturer in Singapore while the other six bitumens were obtained from manufacturers in Mainland China. The results of the basic tests show that all bitumens are Penetration-grade 60–70 and have similar basic properties. The test results comply with the Hong Kong bitumen specification. However, the wax contents of some of the bitumens manufactured from crude oil deposited in China are relatively high. The test results obtained by the dynamic shear rheometer further indicate that the bitumens with low wax content performed better than those with high wax content under a high temperature environment. The test results exhibit relatively good correlation between the wax contents and the rheological properties of the bitumens. Therefore, standards and procedures should be established in Hong Kong to specify requirements on wax content or Performance-grade for bitumen used in road paving.

Keywords: Wax content; Rheological properties; Wax crystallization; Performance-grade; Long-term aging; Complex modulus; Phase angle

1. Introduction

Wax generally refers to all waxlike solids and liquids found in nature and in organic substances that crystallize on cooling and melt on heating [1]. It practically exists in all types of bitumens and in many ways, affects bitumen properties [2]. There is no reason to believe that the structure of wax is less complicated than that of bitumen or of crude oil, from which bitumen is generally manufactured. Chemically, crude oil may be predominantly paraffinic, naphthenic or formed by a combination of the two [3]. Naphthenic-based crude oil often gives a large yield of bitumen that is of good quality, while paraffinic crude oil can either give bitumen of good quality or yield bitumen not suitable for road paving [4]. Though the presence of wax affects the performance of bitumen in many ways, the crystalline nature and nonsticky characteristic of paraffin waxes was believed to have a negative effect on the thermal stability of bitumen and its ability to adhere to aggregates, hence the resistance to rutting and fatigue of the bituminous materials [5]. In this regard, some European countries and China have specified the maximum limit of wax content in bitumen [6,7]. In China, bitumen is classified according to the Penetration-grade and is further classified into different sub-grades based on the wax content and other parameters. The wax content in bitumen has been a major concern in China as the crude oil deposited in China is generally paraffinic, with a relatively high wax content [8,9]. In European countries, bitumen of high wax content is not allowed to be used for road paving. However, bitumen of high wax content can be used in China, although it is not recommended to be used in motorways and heavily trafficked roads.

In Hong Kong, bitumen is imported mainly from Singapore and sometimes from Thailand. The source of the crude oil is from the Middle East and is predominantly of the naphthenic type with a low wax content. Since Hong

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Kong is now a part of the People's Republic of China and geographically adjoins the mainland, bitumen manufactured from crude oil deposited in China is being used more frequently in Hong Kong for road paving.

The use of Penetration-grade 60–70 bitumen has been set as a standard requirement in the local specifications [10]. Though basic tests on bitumen are required to verify its physical properties, no test for determining the wax content is specified and hence it is unable to assess the effect of wax content on the quality of the bitumen. It is considered necessary to investigate the effect of the wax content by means of performance-related tests and to review the local specifications, if necessary.

The main objectives of this study are:

(1) to carry out basic tests and assess the physical properties of seven sources of bitumen with Penetration-grades 60–70;
(2) to compare the wax content of these bitumens and to evaluate their rheological properties under a range of temperatures and different aging conditions;
(3) to evaluate the effect of wax content on performance of bitumen; and
(4) to provide recommendations for the review of local specifications and to provide the basis for further study on establishing performance-based specification for bitumen.

2. Experimental details

2.1. Sources of bitumen

Seven sources of bitumen of similar Penetration-grades were collected for the study, which included six types from China and the conventional type of Penetration-grade 60–70 imported from Singapore. Among the six sources from China, one type (No. 6) was manufactured from crude oil imported from the Middle East as China has imported crude oil from overseas countries to meet the local demand on petrol and other oil refinery products. Three types (Nos. 2, 3 and 7) were manufactured from crude oil deposited in China. The remaining two sources of bitumen (Nos. 4 and 5) were produced by the blending of crude oil from various sources by a manufacturer but they are categorized into two different grades according to the wax content claimed by the manufacturer. Details of the supplier and brand of bitumen are listed in Table 1.

Table 1
Bitumen supplier/brand

Bitumen no.	Supplier/brand
1	Shell (Pen 60/70) (used in Hong Kong and supplied from Singapore)
2	CNOOC (AH-70)
3	Supplier (AH-70, Class B)
4	Maoming (No. 1 bitumen)
5	Maoming (No. 2 bitumen)
6	Sinopec (Zhonghua bitumen)
7	Taizhou (Zhonghai bitumen)

2.2. Test methods

Test specimens were prepared according to the Chinese standard T0602-1993. Test methods used in this study for determining the basic properties of bitumens include the penetration at 25 °C (ASTM D5-94), softening point (BS 2000-1993), ductility (ASTM D113-86), viscosity at 60 °C (ASTM D2171-94), thin-film oven test for retained penetration (ASTM D1754-97), loss on heating (BS 2000-1993), solubility (BS 2000-1983) and relative density (ASTM D3289-85). These test methods are specified in the local specifications [10].

The distillation method according to the Chinese standard T0615-2000 was adopted in this study to determine the wax content as most of the bitumens were sourced from the Chinese manufacturers. For each bitumen, two specimens were prepared for testing. The tests were carried out using the bitumen wax content analyzer, Model SYD-0615, which consisted of a distilling system, a thermo-regulator and a compressor–refrigerator. The three major processes in the distillation method are:

(1) extraction of bitumen oil from bitumen by distillation;
(2) extraction of wax from bitumen oil, which involves the use of a cooling bath at a very low temperature of –20 °C for the wax crystallization followed by filtration; and
(3) dissolving crystallized wax in the filter by a solvent and removing the solvent from the mixture in a heating chamber.

The tests for determining the basic properties and wax content of bitumen are not directly related to its performance in pavement materials. These tests are not able to provide information related to the rheological properties of bitumen under different loading, loading time and thermal conditions. However, measurements of these properties have been a standard practice in many countries in order to assess the quality of bitumen. In the US, Performance-grade (PG) was developed under the Strategic Highway Research Program (SHRP) [11] for assessing the rheological properties of bitumen. The dynamic shear rheometer (DSR) test for assessing the rheological properties of bitumen was developed as part of the Superpave bitumen specifications.

Rheological properties of bitumen were determined by the DSR under three different conditions including the original, the aging that occurs during the mixing, laying and compaction process, and finally the long-term aging condition. The complex modulus G^* and phase angle δ of the bitumen within a range of temperatures under each condition were determined from the DSR test. For the prepara-