MAREK IWAŃSKI*), GRZEGORZ MAZUREK

Kielce University of Technology
Chair of Transportation Engineering
Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland

Rheological characteristics of synthetic wax-modified asphalt binders

RAPID COMMUNICATION

Summary — This paper presents the test results of modification of bitumen 35/50 with synthetic aliphatic wax (SW) obtained during the Fisher-Tropsha synthesis. The aim of the modification is an improvement of rheological properties of the bitumen as well as possibilities to lay the asphalt pavement at decreased compaction temperature by up to 30 °C. Experiments have confirmed that the modification of asphalt with synthetic wax resulted in beneficial changes in complex modulus (G^*) and phase angle (δ) of modified bitumen 35/50. In consequence, the modified bitumen increased resistance of the asphalt pavement to permanent deformation and decreased the compaction temperature to 100 °C. On the basis of the MSCR test it was revealed that the existence of aliphatic wax in bitumen compound affected the compliance (J_{nr}) and elastic recover (R) of bitumen. It resulted in an increase in the resilient modulus of elasticity of asphalt pavement and also it will contribute to its higher durability.

Keywords: asphalt binders, synthetic wax, complex modulus, phase angle, MSCR test.

CHARAKTERYSTYKA REOLOGICZNA LEPISZCZA ASFALTOWEGO MODYFIKOWANEGO WOSKIEM SYNTETYCZNYM

Streszczenie — W pracy przedstawiono wyniki badań modyfikacji asfaltu drogowego 35/50 alifatycznym woskiem syntetycznym otrzymanym w wyniku syntezy Fishera-Tropscha. Modyfikacja miała na celu poprawę właściwości reologicznych lepiszcza i tym samym możliwości wykonania nawierzchni asfaltowej w temperaturze obniżonej o ok. 30 °C i jednoczesnego zwiększenia trwałości tej nawierzchni. Eksperymenty potwierdziły, że modyfikacja asfaltu woskiem syntetycznym powoduje korzystne zmiany modułu zespolonego (G^*) i kąta przesunięcia fazowego (δ) modyfikowanego asfaltu 35/50. W konsekwencji takiej modyfikacji wzrasta sztywność asfaltu w wysokich temperaturach eksploatacyjnych. Wzrost sztywności asfaltu powoduje zwiększenie odporności na deformacje trwałe mieszanki mineralno-asfaltowej. Przemiana fazowa wosków syntetycznych w temperaturze powyżej 100 °C powoduje wzrost ich objętości oraz obniżenie temperatury zagęszczania mieszanki mineralno-asfaltowej do 100 °C. Na podstawie testu MSCR (wg AASHTO TP70) wykazano również, że w wyniku modyfikacji asfaltu 35/50 następuje korzystna zmiana jego podatności (J_{nr}) oraz nawrotu sprężystego (R). W rezultacie tego asfalt będzie odznaczał się wyższym poziomem lepkości struktury nienaruszonej, co w konsekwencji spowoduje wzrost modułu sztywności sprężystej mieszanki mineralno-asfaltowej i jej niższą wrażliwość na efekty przeciążenia wywołane ruchem pojazdów.

Słowa kluczowe: lepiszcze asfaltowe, wosk syntetyczny, moduł zespolony, kąt przesunięcia fazowego, test MSCR.

INTRODUCTION

The purpose of assessment of bitumen rheology with the synthetic Fischer-Tropsch (FT) wax was to predict the resistance of the asphalt concrete to permanent deformation. The main task of the bitumen in the asphalt mixture is a covering of the aggregate and its mix to each other which leads to creation specific properties of the bituminous composite. In order to allow this process to occur, it is necessary to bring the bitumen to the adequately low level of viscosity in the range between 2 and 20 Pa · s. For this purpose it is commonly necessary to heat the bitumen up to 160—180 °C depending on the type of bitumen. This process is energy consuming and associated

*) Author for correspondence; e-mail: iwanski@tu.kielce.pl

with massive emission of greenhouse gases. Moreover, permanent heating of the bitumen may intensify its aging process which affects visco-elastic properties of the bitumen and decreases the asphalt pavement durability.

Improvement of properties of the bituminous composite at lower temperatures is possible through the application of low-viscosity modifiers, which contain aliphatic synthetic wax obtained during the Fischer--Tropsch (FT) synthesis. They are distinguished from paraffin waxes contained actually in the bitumen in respect of composition and interaction as well [1]. FT synthetic waxes have a microcrystalline structure and they consist of particles with a large number of carbon atoms, up to 100 [2, 3]. Due to its morphology there is a possibility to increase the viscosity in temperatures below 100 °C and its softening temperature (range of non-Newtonian state) as well [4]. They act as a fine filler, enhancing the resistance to permanent deformation of the asphalt pavement. At the temperature above 100 °C, FT wax dramatically reduces the viscosity of bitumen which lowers the compaction temperature of the asphalt mix by up to 30 °C. An important element of the modification process is proper recognition of the basic rheological properties of the bitumen which facilitates a prediction of the behavior of the asphalt mix *in situ* condition.

EXPERIMENTAL

Materials and sample preparation

In the studies FT synthetic wax (SW) as a low-viscosity modifier, obtained from Sasol Company, was applied. As a bitumen (B) it was used the bitumen of 35/50 penetration grade obtained from ORLEN Asfalt Sp. z o.o. (Płock).

The modifier, which appears in the form of granules, has been dosed in the range from 1.5 to 4.0 % by weight of the B with steps of 0.5 %. The preparation process included separation of asphalt samples, for each level of modification, in an amount of 250 g. The sample was heated up to 155 °C and held in this state for 30 min. The next step was a blending, in the constant temperature, at 400 rpm. This process was necessary to reach the homogenization of B and SW. Prepared samples of the bitumen met the requirements of PN-EN 12594:2004 standard.

Methods of testing

In order to investigate the effectiveness of the application of the FT synthetic wax into bitumen it was made the measurement of the complex modulus (G^*) and phase angle (δ) at 60 °C and subsequently the MSCR test (Multiple Stress Creep Recovery Test of Asphalt Binder) [5] was carried out.

Complex modulus and phase angle are an assessment of the visco-elastic behavior of bitumen listed in the Strategic Highway Research Program (SHRP) methodology [6, 7]. The interrelation between the complex modulus and the phase angle provides an evaluation of the elastic and viscous part of the binder. Both these relationships change depending on the temperature and the loading time.

MSCR test was performed according to AASHTO TP70 methodology. It was developed as a verification of the complex modulus and phase angle prescribed by the SHRP program. It allows assessment of the nonlinear behavior of asphalt and stands out for a high correlation with results obtained from rutting tests for asphalt mixes. The test has been proposed to predict the susceptibility to surface damage due to high ambient temperatures when the bitumen becomes a viscous liquid [8]. This method allows evaluating the compliance and the relaxation of the bitumen under simulated loading conditions close to real conditions in wide range of stresses. Using the viscometer, a one second creep load was applied to the asphalt binder sample. Then the load was removed, the sample was allowed to recover for 9 seconds. The test was started with the application of a low stress (100 kPa) for 10 creep/recovery cycles then the stress increased to 3200 kPa and was repeated for additional 10 cycles.

RESULTS AND DISCUSSION

The results of G^* and δ of the investigation on bitumen 35/50 (B) modified with FT synthetic wax (SW) were shown in Figure 1.

The test results indicate that the complex modulus (G^*) increases with the load frequency (Fig. 1a). However, regardless of the temperature, the low-viscosity modifier affected the increase of the level of the complex modulus in each variant of dosage. All modified B samples and the reference neat B had a value of (elastic part of) $G^*/\sin(\delta) >$ 1000 Pa at the frequency of 1.56 Hz what corresponds to the loading time at 60 km/h according to the SHRP. Compared to the neat B the level of G^* for 3.0 % of the modifier increased 7 times. This level of bitumen hardening guarantees low susceptibility of asphalt concrete to permanent deformation within the confines of SHRP program [7]. Nature of the dynamics of the G^* and the level of its change (Fig. 1a) indicates that in the range between 0.001 to 10 Hz there is a statistically significant increase in the modulus G^*. It must be noted that regardless of the amount of low-viscosity modifier (the whole experiment domain), the growth rate with relation to the reference sample — neat B, is proportional. Variations in the frequency are similar but in some cases are even lesser. It probably corresponds to the quality of fine microcrystalline synthetic waxes dispersion, whose presence does not impair the integrity of the colloidal structure of the bitumen. With respect to δ (Fig. 1b) the increase in value of SW content causes reduction in this physical quantity, in some cases, up to 50 %. It could be expected that B modified with SW behaves more elastic with a high capacity to

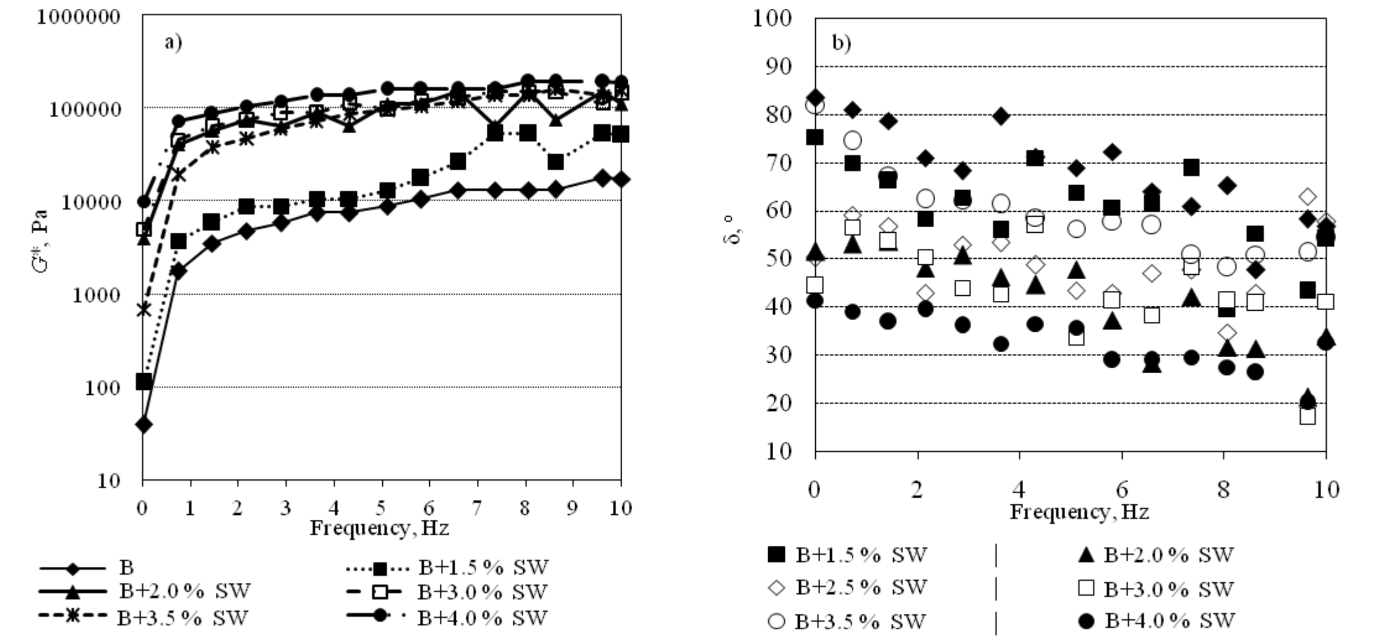

Fig. 1. The influence of frequency and FT synthetic wax content on change of: a) complex modulus (G) in 60 °C, b) phase angle (δ) in 60 °C*

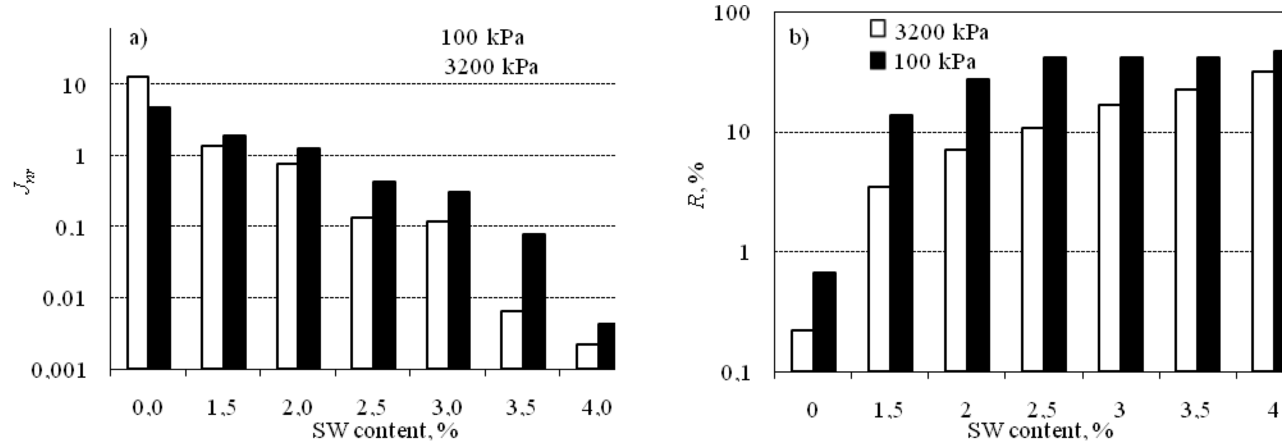

Fig. 2. The influence of FT synthetic wax content on compliance (J_{nr}) (a) and recovery (R) (b) according with MSCR test

accumulate and release energy coming from the axle loads.

The results of compliance (J_{nr}) and recovery (R) according to MSCR were shown in Figure 2.

In the MSCR test the increase of the strains causes a decrease in J_{nr} of prepared samples according to the exponential function model $y = a \cdot e^{-bx}$ [5]. Thus, the increase in the quantity of SW crystals in B should decrease growth of this phenomenon. It should be expected at least a linear increase in rut resistance due to reducing of J_{nr} value of an asphalt sample. For these two ranges of stress the change in the compliance had a similar trend (Fig. 2a).

Tested samples were characterized by an increase in R at a low stress (Fig. 2b). The value of the elastic recovery, according to MSCR, increases as the SW content increased. This fact fully correlates with the results of J_{nr} of samples and it indicates to extension of the stress range of the linear visco-elastic behavior of the asphalt. The results with application of the stress level of 3200 MPa show some variation in the nature of recovery of bitumen. It can be concluded that the dosage of the SW in the amount of 2.5 % can significantly improve the resistance of bitumen to permanent deformation in the asphalt pavement, giving a more elastic behavior at 60 °C.

CONCLUSIONS

On the basis of the test results the following conclusions were made:

— the increase in the amount of FT synthetic wax has an influence on the rheological characteristics of the bitumen 35/50,

— the presence of the FT synthetic wax affected the level of G^* value,

— the decrease in the phase angle, due to the addition of FT synthetic wax, caused the more elastic behavior of the neat bitumen 35/50,

— the MSCR test revealed the significant decrease in J_{nr} value of bitumen 35/50 as a result of FT synthetic wax modification,

— the *R* value has been increased during increasing of the synthetic wax FT content.

REFERENCES

1. Polacco G., Filippi S., Paci M.: *Fuel* 2012, **95**, 407.
2. Butz T., Rahimian I.: *J. Appl. Asphalt Binder Technol.* 2001, **1**, 70.
3. Xiaohu L., Langton M., Oloffson P.: *J. Mater. Sci.* 2005, **40**, 1893.
4. Silva H., Oliviera J., Peralta J., Zoorob S.: *J. Mater. Civ. Eng.* 2012, **24**, 1621.
5. „The Multiple Stress Creep Recovery (MSCR) Procedure", Technical-Brief, FHWA-HIF-11-038, April 2011.
6. Gaweł I., Kalabińska M., Piłat J.: „Asfalty drogowe", Wydawnictwo Komunikacji i Łączności, Warszawa 2001, p. 255.
7. Sybilski D.: Prace IBDiM, Zeszyt 50, Warszawa 2000, pp. 8—177.
8. Bahia H. U.: „Modeling of Asphalt Concrete", McGraw--Hill, 2004, pp. 11—64.

Received 17 IV 2012.