A COMPARISON OF THE 2PB-TR AND THE IT-CY METHODS FOR DETERMINING ASPHALT MIXTURE STIFFNESS

Jiří Pospíšil*,[1], Jan Valentin[1]

*jiri.pospisil.1@fsv.cvut.cz
[1]Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7/2077, Prague 6 – Dejvice

Abstract

In the Czech Republic, an intensive preparation of the construction of high-speed lines according to the principles adopted from France has currently been underway. Its substructure is among others to be made of a layer of asphalt concrete. However, the stiffness requirements of such an asphalt mixture cannot simply be taken from the French standards because in the Czech Republic, a different type of test methods for its determination is more commonly used. This paper describes an experimental study that compares the results of the asphalt mixture stiffness determined by the 2PB-TR method used in France and the IT-CY method which is frequently used in the Czech Republic (as well as in the United Kingdom). As part of the study evaluation, a mutual correlation between the individual methods is found for the results.

Keywords

Asphalt mixture stiffness, complex modulus, stiffness modulus, high-speed line, viscoelastic material

1 INTRODUCTION

Asphalt concrete is a composite material and in Europe, it is used in railway structures as well as in road structures. In railway structures, it is mostly used in the railway substructure as a material for the upper sub-ballast layer [1]. Its greatest advantages include its high stiffness and low thermal conductivity which leads to significant savings on the total thickness of the sub-ballast layers compared to conventional structures made only of aggregate [1]. It is mainly used for the construction of new sections of the high-speed lines in France [2] and is also expected to be a standard solution in the Czech Republic [3]. In the years 2019 to 2020, as part of the cooperation between the Czech and French national railway company, the French know-how on high-speed lines was taken over and adapted to Czech conditions. Based on these principles, preparation of the construction of high-speed lines in the Czech Republic is currently underway [3].

The requirements for the properties of asphalt concrete in France are defined by the national annex of the standard NF EN 13108-1 [4]. In the Czech Republic, these requirements have been defined since 2021 by Annex F of the ČSN 73 6120 standard [5] and Annex 12 of the SŽ S4 regulation [6] and they only apply to tracks with speeds up to and including 200 km·h^{-1}. However, the requirements for the properties of asphalt concrete for the Czech high-speed lines cannot simply be taken from France, as different test procedures are standardized in both countries for determining the mechanical and functional properties of asphalt mixtures.

One of these test procedures is the determination of the stiffness of asphalt mixtures. While standard [4] states the requirement for the complex modulus determined by the 2PB-TR method according to Annex A of the EN 12697-26+A1 standard [7], the standard [5] states the requirement for the stiffness modulus determined by the IT-CY method according to Annex C of the standard [7]. For that reason, an experimental study was carried out, the aim of which was a practical comparison and finding of a mutual correlation between the individual methods.

2 METHODOLOGY

A total of 11 asphalt mixtures listed in Tab. 1 including their basic descriptive properties were tested. These are mixtures commonly used in civil engineering. The results of the ACL 16+ KYT mixture (marked in *italics* in the tables) were not included in the study evaluation due to their deviation from the trend. The paving grade bitumen 50/70 or 70/100 according to the EN 12591 standard [8], or the polymer-modified bitumen PMB 25/55RC

DOI 10.13164/juniorstav.2024.24022

or the PMB 45/80-65 according to the EN 14023+A2 standard [9] were used as an asphalt binder in the mixtures. The ACP 16 50RA AN mixture contained an Antistrip rejuvenator to soften the binder of aged R-material.

Tab. 1 List of tested asphalt mixtures.

Asphalt mixture	Asphalt binder	Binder content [10] (%)	Bulk density [11] (g·cm^{-3})	Void characteristic [12] (%)
ACO 11+ NET	*50/70*	*5.9*	*2.665*	*3.58*
ACO 11+ CHV	*50/70*	*N/A*	*2.319*	*N/A*
ACO 11+ MAR	*50/70*	*5.9*	*2.596*	*1.08*
ACO 11+ 25RA	*50/70*	*5.6*	*2.379*	*4.28*
ACO 11+ 30RA	*70/100*	*5.8*	*2.423*	*3.45*
SMA 11S 15RA	*PMB 45/80-65*	*6.3*	*2.409*	*3.47*
ACL 16+ KYT	*50/70*	*4.1*	*2.431*	*5.04*
ACL 16+ MAR	*50/70*	*4.6*	*2.600*	*2.62*
ACL 16S 50RA	*PMB 25/55RC*	*4.3*	*2.407*	*5.31*
ACP 16+ 50RA	*70/100*	*3.9*	*2.400*	*5.90*
ACP 16 50RA AN	*70/100*	*3.9*	*2.387*	*6.40*

From each mixture, eight trapezoidal specimens of 250 mm in length, 25 mm in thickness and of base widths of 75 mm and 25 mm cut from a plate prepared by a roller compactor [13], and six cylindrical specimens of 100 mm in diameter and 65 mm to 75 mm in height prepared by an impact compactor [14] were made. In accordance with the standard [5], specimens of mixtures with paving grade bitumen were made at a mixture temperature of 150 °C. Furthermore, specimens of mixtures with polymer-modified bitumen at a mixture temperature of 155 °C were made.

For each trapezoidal specimen, its stiffness at 15 °C was determined using the 2PB-TR method according to Annex A of the standard [7], and for each cylindrical specimen, its stiffness at 0 °C, 15 °C and 27 °C was determined using the IT-CY method according to Annex C of the standard [7]. The stiffness at 0 °C and 27 °C was determined to calculate the temperature susceptibility of the mixture, which was thought to influence the results. Each mixture is thus represented by the arithmetic mean of the stiffness values determined by the two methods for each of the respective test specimens. These values were further statistically evaluated – using the least squares method, regression equations were found for the stiffness results determined by the individual methods.

3 RESULTS

The determined values of the asphalt mixture stiffness are shown in Tab. 2. Fig. 1 shows these values graphically, including the linear regression equations and their coefficients of determination R^2. For regression equations in the form $y = Ax + B$, where A is a slope and B is an y-intercept of the equation, the value of x or y expresses the value of the complex modulus determined by the 2PB-TR method or the value of the stiffness modulus determined by the IT-CY method. Evaluating exponential, logarithmical or polynomial regression equations turned out to be pointless – the values of the coefficients of determination R^2 do not differ significantly. However, it is possible that with a larger statistical set, an evaluation by non-linear regression equations would make sense as well as an evaluation of the results separately for mixtures with the same nominal aggregate size.

DOI 10.13164/juniorstav.2024.24022

Tab. 2 Results of asphalt mixtures complex modulus (2PB-TR) and stiffness modulus (IT-CY).

Asphalt mixture	**Complex modulus at 15 °C, 2PB-TR (MPa)**					**Stiffness modulus, IT-CY (MPa)**		
	5 Hz	**10 Hz**	**15 Hz**	**20 Hz**	**25 Hz**	**0 °C**	**15 °C**	**27 °C**
ACO 11+ NET	*8 329*	*8 920*	*9 276*	*9 873*	*9 847*	*N/A*	*8 844*	*N/A*
ACO 11+ CHV	*6 139*	*6 727*	*7 052*	*7 302*	*7 542*	*16 659*	*7 988*	*3 366*
ACO 11+ MAR	*8 421*	*9 116*	*9 491*	*9 729*	*9 978*	*22 563*	*8 952*	*3 393*
ACO 11+ 25RA	*7 235*	*7 974*	*8 386*	*8 658*	*8 824*	*20 851*	*10 375*	*2 466*
ACO 11+ 30RA	*6 395*	*7 098*	*7 382*	*7 642*	*7 955*	*18 353*	*6 846*	*2 042*
SMA 11S 15RA	*8 835*	*9 590*	*10 045*	*10 347*	*10 685*	*17 510*	*5 507*	*2 991*
ACL 16+ KYT	*4 916*	*5 222*	*5 430*	*5 588*	*5 845*	*21 216*	*10 932*	*4 441*
ACL 16+ MAR	*8 826*	*9 728*	*10 150*	*10 495*	*11 517*	*22 612*	*9 702*	*3 108*
ACL 16S 50RA	*10 689*	*11 227*	*11 501*	*11 659*	*11 953*	*26 906*	*17 897*	*9 954*
ACP 16+ 50RA	*9 446*	*9 810*	*10 079*	*10 281*	*10 730*	*22 919*	*13 195*	*4 606*
ACP 16 50RA AN	*9 139*	*9 817*	*10 188*	*10 402*	*10 673*	*21 592*	*13 340*	*4 642*

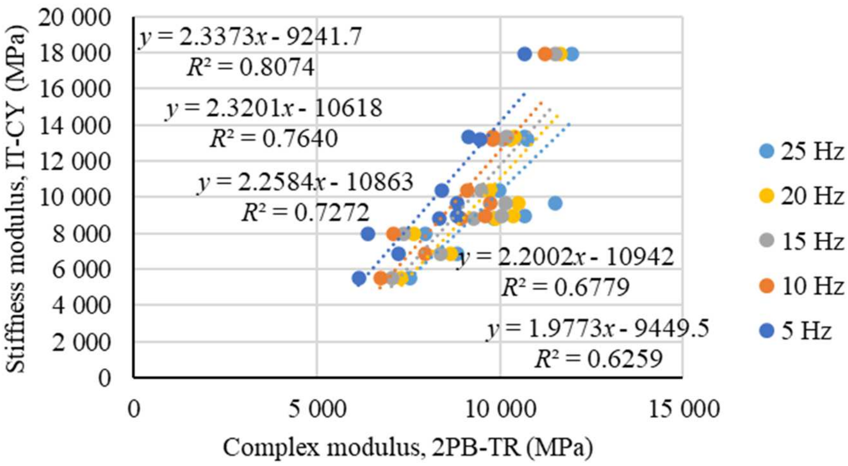

Fig. 1 Results of asphalt mixtures complex modulus (2PB-TR) at 15 °C and stiffness modulus (IT-CY) at 15 °C.

According to the values shown in Tab. 2, no rule that the values of the stiffness modulus (IT-CY) at 15 °C are higher than the values of the complex modulus (2PB-TR) at 15 °C and any loading frequency can be observed. However, it can be observed in Tab. 2 and in Fig. 1 that the value of the complex modulus (2PB-TR) increases with increasing loading frequency. Apparently, this shows the effect of the dynamic loading of viscoelastic material when the imaginary component of the complex modulus increases with increasing frequency [15]. At the same time, the regression equations shown in Fig. 1 indicate that the result of stiffness modulus (IT-CY) is given by the combination of a multiple of complex modulus (2PB-TR) and its difference as well – the slopes of the equations are close to 2 and the *y*-intercepts are close to 10 000 MPa. While the slope value decreases with increasing loading frequency, the *y*-intercept value appears to be independent of loading frequency.

The regression equations were also evaluated for the loading frequency dependence of the complex modulus (2PB-TR) at 15 °C and the asphalt mixture temperature dependence of the stiffness modulus (IT-CY). For the loading frequency dependence of the complex modulus (2PB-TR), logarithmical equations turned out to be most suitable. In case of the asphalt mixture temperature dependence analysed for the stiffness modulus (IT-CY) which expresses the temperature susceptibility of the mixture, linear equations are evaluated because for each mixture, there were only three mean values determined. The equations including coefficients of determination are shown in Fig. 2 and Fig. 3.

DOI 10.13164/juniorstav.2024.24022

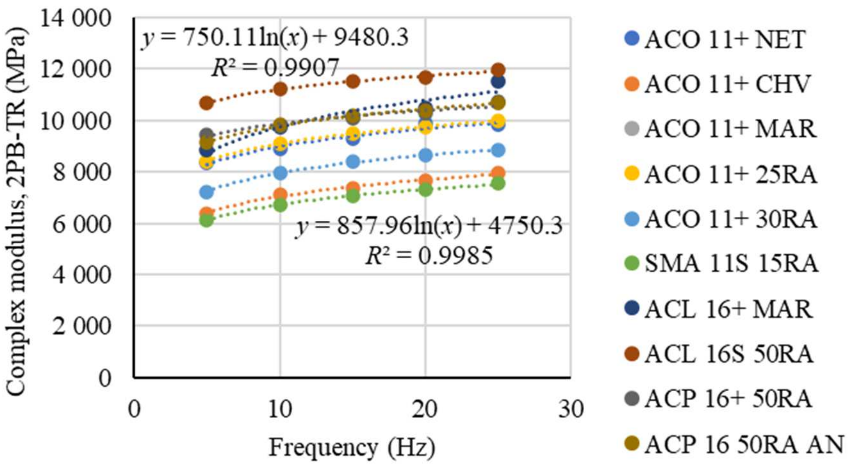

Fig. 2 Loading frequency dependence of the complex modulus (2PB-TR) at 15 °C.

The loading frequency dependence of the complex modulus (2PB-TR) turns out to be logarithmic. However, this certainly applies only to the displayed limited domain from 5 Hz to 25 Hz and the curve would have a different shape for higher or lower frequencies because with a decreasing value of the loading frequency, the complex modulus (2PB-TR) value would gradually decrease to negative values and approach minus infinity, which is unrealistic. The loading frequency basically simulates the frequency of repetitive loading of the viscoelastic material. At very high frequencies when individual load cycles are repeated in short periods, the modulus characteristic at a given temperature will most likely begin to approach the limiting maximum so the asphalt mixture behaves as if under constant load. The logarithmic curve thus probably forms only a part of a more general curve defined for a larger domain of loading frequencies. However, this theory about the dependence of the complex modulus of the asphalt mixture as a viscoelastic material on the loading frequency would have to be verified by expanding the domain of loading frequencies or by determining the complex modulus at different temperatures with the same loading frequency domain and generating a master curve by using the time-temperature superposition principle.

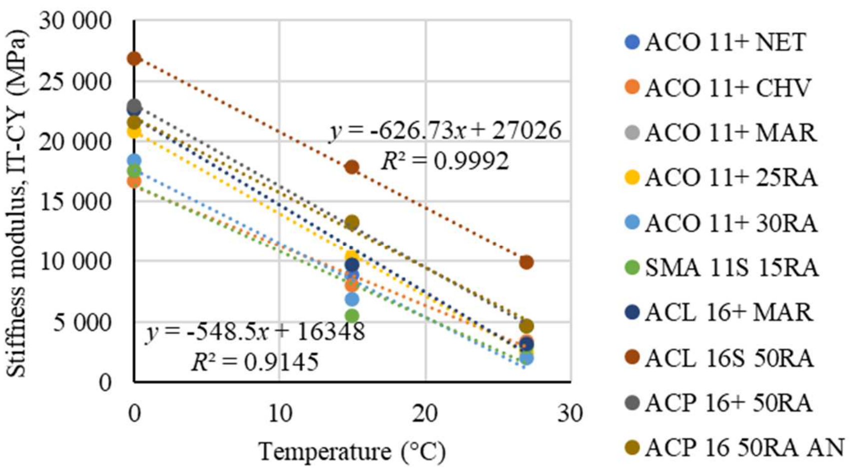

Fig. 3 Asphalt mixture temperature dependence of the stiffness modulus (IT-CY).

In this study, the temperature susceptibility of the asphalt mixture shown in Fig. 3 was not confirmed to affect the relationship between the complex modulus (2PB-TR) and the stiffness modulus (IT-CY) result. The temperature susceptibility of the asphalt mixture depends primarily on the composition of the mixture (type and content of asphalt binder, aggregate size distribution curve, void characteristic) [16] and none of the regression equations differs significantly. That is why the effect of temperature susceptibility on asphalt mixture stiffness cannot be well demonstrated.

DOI 10.13164/juniorstav.2024.24022

4 DISCUSSION

The increasing values of the slopes of linear regression equations with decreasing loading frequency (see Fig. 1) show that at lower loading frequencies limiting 5 Hz, the increase in stiffness of the asphalt mixture is pronounced better than at higher loading frequencies limiting 25 Hz. When designing the mixture, it is necessary to consider the real loading frequency of the sub-ballast or pavement layer given by the speed of a passing vehicle. However, the difference between the values of the complex modulus (2PB-TR) and the stiffness modulus (IT-CY) given by the *y*-intercept value is not subject to any trend depending on the loading frequency (see Fig. 1), which proves that the result of the asphalt mixture stiffness also depends on parameters other than loading frequency [15].

Fig. 1 shows the results of the complex modulus (2PB-TR) and the stiffness modulus (IT-CY) at 15 °C. The coefficient of the determination R^2 values ranges between 0.6 for the loading frequency limiting 25 Hz and 0.8 for the loading frequency limiting 5 Hz. It can also be expected that at lower specimen temperatures, these values will be higher and vice versa, according to the dynamic modulus (4PB-PR) and the stiffness modulus (IT-CY) results comparison [16]. Therefore, the loading frequency and the temperature of the tested specimens probably affect the stability of the asphalt mixture stiffness and lower measurement deviations can be expected at lower loading frequencies or lower temperatures.

5 CONCLUSION

As part of the study, 88 trapezoidal and 66 cylindrical test specimens of 11 different asphalt mixtures were prepared. Based on the results of laboratory tests, the complex modulus values at different frequencies and the stiffness modulus values at different temperatures were determined by the 2PB-TR method and the IT-CY method to determine the asphalt mixture stiffness. These values were statistically evaluated and regression equations and their coefficients of determination R^2 were defined.

As regards the production of the test specimens and testing, the IT-CY method is faster, easier and thus also cheaper. In the Czech Republic, this method is also historically established and its use is likely to be preferred in the future as well. The results of this study can be thus used to reproduce the stiffness requirements for asphalt concrete for high-speed lines in France stated in standard [4] in the Czech environment. This standard states the requirement for a minimum value of 11 000 MPa of the complex modulus at 15 °C and 10 Hz according to Annex A of standard [7], which according to the regression equation in form $y = 2.3201x - 10618$ that follows the results of the study and is shown in Fig. 1, corresponds to a value of 14 903 MPa of the stiffness modulus according to Annex C of standard [7]. The value of the coefficient of determination R^2 of this regression equation is 0.7640 so the accuracy of the result is satisfactory.

When evaluating the results, a logarithmic dependence of the complex modulus (2PB-TR) on the loading frequency was also found. It is probably only part of a more general function relevant only to the domain of loading frequencies from 5 Hz to 25 Hz. However, the extension of the range of loading frequencies and the study of their effect on the asphalt mixture complex modulus value may be the subject of further research.

Acknowledgement

This paper was funded by the Student Grant Competition of the Czech Technical University in Prague as part of the project No. SGS23/046/OHK1/1T/11.

References

[1] European Asphalt Pavement Association (EAPA). Asphalt in Railway Tracks. Technical Review. Brussel: EAPA, 2021
[2] HÉRITIER Bernard. GB sous ballast: une solution innovante pour la grande vitesse. *Revue générale des routes et de l'aménagement.* October 2020, vol. 976. ISSN 2970-4510
[3] SŽ PO-16/2020-GŘ. High-Speed Lines Design Manual for the Planning Permit Level. Prague: Správa železnic, July 2021
[4] NF EN 13108-1. Bituminous mixtures — Material specifications — Part 1: Asphalt concrete. Saint-Denis: AFNOR, February 2007
[5] ČSN 73 6120. Road building – Other pavement courses – Construction and conformity assessment. Prague: Czech Office for Standards, Metrology and Testing, August 2021
[6] SŽ S4. Railway substructure. Amendment No. 1. Prague: Správa železnic, January 2024
[7] ČSN EN 12697-26+A1. Bituminous mixtures — Material specifications — Part 26: Stiffness. Prague:

Czech Office for Standards, Metrology and Testing, June 2023
[8] ČSN EN 12591. Bitumen and bituminous binders – Specifications for paving grade bitumens. Prague: Czech Office for Standards, Metrology and Testing, September 2009
[9] ČSN EN 14023+A2. Bitumen and bituminous binders – Specification framework for polymer modified bitumens. Prague: Czech Office for Standards, Metrology and Testing, February 2019
[10] ČSN EN 12697-1. Bituminous mixtures – Test methods – Part 1: Soluble binder content. Prague: Czech Office for Standards, Metrology and Testing, October 2020
[11] ČSN EN 12697-6. Bituminous mixtures – Test methods – Part 6: Determination of bulk density of bituminous specimens. Prague: Czech Office for Standards, Metrology and Testing, March 2021
[12] ČSN EN 12697-8. Bituminous mixtures – Test methods – Part 8: Determination of void characteristics of bituminous specimens. Prague: Czech Office for Standards, Metrology and Testing, February 2020
[13] ČSN EN 12697-33+A1. Bituminous mixtures – Test methods – Part 33: Specimen prepared by roller compactor. Prague: Czech Office for Standards, Metrology and Testing, June 2023
[14] ČSN EN 12697-30. Bituminous mixtures – Test methods – Part 30: Specimen preparation by impact compactor. Prague: Czech Office for Standards, Metrology and Testing, February 2020
[15] SAUZEAT Cedric, DI BENDETTO Hervé. Tridimensional Linear Viscoelastic Behavior of Bituminous Materials. In: HUANG Shin-Che, DI BENDETTO Hervé. *Advances in Aphalt Materials. Road and Pavement Construction* [online]. Woodhead Publishing, 2015, pp. 59–95. [Accessed 2023-10-30]. ISBN 978-0-08-100269-8. Available at: https://doi.org/10.1016/B978-0-08-100269-8.00003-9
[16] BELHAJ Majda, VALENTIN Jan, VACKOVÁ Pavla. Comparative Study of the Stiffness Modulus Using Selected Test Methods – 4-point Bending Test and Indirect Tensile Test in the Pavement Layer. In: *Juniorstav 2023. Proceedings of the 25th International Scientific Conference of Civil Engineering for Ph.D. Students.* Brno: ECON publishing, 2023, pp. 469–476. ISBN 978-80-86433-80-6

DOI 10.13164/juniorstav.2024.24022