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Road and Rail Infrastructure III

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INDIRECT TENSILE TEST OF ASPHALT MIXTURE STIFFNESS MODULUS

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Abstract

Mechanistic – empirical calculation method is applied worldwide in calculation of new pavement structures and evaluation of the existing ones. The majority of mechanistic methods of dimensioning is based on the evaluation of the structural behaviour of structures, i.e. critical relation of stress and deformity during application of certain load on the pavement. Stiffness of asphalt mixtures is an essential parameter in evaluation of induced load, temperature stress and distribution of deformities in pavement structure. In certain parts of Croatia the average maximal summer temperatures on pavement surface reach approximately 40°C. At such high temperatures, the asphalt stiffness modulus is significantly decreased and there is a high possibility of occurrence of driving surface plastic flow in the form of rutting. During winter, temperatures decrease to -10°C and the combination of low temperatures and cyclic changes, with very high stiffness modulus, may cause cracks in asphalt pavement. Systematic measurement of asphalt mixture stiffness modulus was carried out within the research through application of the indirect tensile test method at temperatures those mixtures would be exposed to during their project life span. This Paper presents elaboration of stiffness modulus test results achieved through application of the indirect tensile test on several types of asphalt mixtures at different temperatures. Furthermore, it presents the stiffness modulus test results for several asphalt concrete mixtures AC 11 of different composition, i.e. of different physical – mechanical properties.

Keywords: stiffness modulus, asphalt mixture, indirect tensile test, rutting

1 Introduction

The goal of this research was to determine the stiffness modulus at mixture exploitation temperatures for several types of hot asphalt mixtures used today for construction of roads in Croatia, with the purpose of obtaining input data for control of stresses and strains occurring in pavement structure. Furthermore, another purpose was to establish how the mixture composition effects variation of stiffness modulus.
Until this research, obsolete and imprecise data on material properties were used in Croatia, obtained based on testing of dynamic modulus of elasticity in dependence on temperature, conducted almost 50 years ago [1] (Dormon and Edwards, 1967).
The effect of temperature variation to the stiffness modulus of seven different asphalt mixtures was determined within the first part of testing, resulting in curves representing variation of stiffness modulus of those mixtures due to temperature variation. The testing temperatures were within the limits of temperature range occurring on pavements in Croatia during the course of one year. The effect of asphalt-concrete AC 11 mixture variation to the stiffness was tested in the second part of the testing.

2 Indirect tensile test

Asphalt mixture stiffness modulus may be measured in several ways, according to the standard HRN EN 12697-26 [2]. The indirect tensile test was selected (Appendix C of the abovementioned standard), due to the simplicity and quickness of measurement, as well as preparation of specimen (in comparison to other measurement methods defined in the standard) and due to the availability of measurement equipment.
The majority of asphalt mixtures is not elastic but goes through some form of plastic deformity after application of load. However, if the load is low in comparison to the strength of material and if it is applied repeatedly, the deformity is almost completely reversible after each repetition.
Resilient or reversible modulus is the ratio of repeated stress and reversible (resilient) relative strain, due to the brief repeated load application which corresponds to the load from wheels of moving vehicles. Resilient modulus describes the efficiency of different pavement structure courses to distribute the stresses, resulting from traffic load, within the pavement structure. It is used in the theory of elasticity for forecasting of reversible relative deformity or displacement during mechanistic projecting of flexible pavement structures.
In laboratory the resilient modulus of asphalt mixtures is most frequently determined through the indirect tensile test (HRN EN 12697-26, Appendix C). The testing is non-destructive since the stresses are very low.
The indirect tensile test is used for measurement of small deformities of asphalt specimens. It is a non-homogenous testing, with assumption that the tested material is isotropic material with constant Poisson ratio. It is conducted by application of repeating impulse compressive load on two diametrically opposed „strips“ of a cylindrical specimen. The central part of the specimen is then submitted to predominantly constant tensile stress in diametrical plane which connects the „load strips“. This results in reversible deformity in horizontal diametrical plane.
In case the vertical variation of diameter is not measured, the assumed value of the Poisson coefficient for all asphalt materials is 0.35 for all temperatures [2]. Due to the viscoelastic properties of asphalt mixtures, duration of load application effects significantly the value of stiffness modulus and the goal is to achieve as realistic as possible simulation of actual conditions of load. The stress in pavement is maximal at the point above which the load is applied while it decreases with the distance from this point. Due to that, the assumed load pulse during testing is a triangular, square or sinusoidal function. According to standard [2] this procedure is classified under tests with sinusoidal load. It is recommended that the shape of load curve is approximately a wave with load shape factor 0.6. Since the pulse tests were developed for „inspection“ measurements, only duration and the maximal applied value of repeated load are controlled during testing and not the shape of the wave. However, the shape of the load curve is recorded during measurement and the obtained stiffness modulus is corrected subsequently through an equation to the pre-defined load shape factor 0.6.

3 Testing programme

All the tests were conducted from the year of 2010 to 2012 in the Laboratory for asphalt and road soil mechanics, Institut IGH d.d. Zagreb. Asphalt mixture specimens were sampled on several actual construction sites, in compliance with the standard (HRN EN12697-27). Afterword, the specimens were prepared according to the standard HRN EN12697-28 and the testing of physical – mechanical properties of asphalt mixtures was conducted on them. The following was determined: soluble share of binder (HRN EN12697-1), grain size distribution (HRN EN12697-2) and thickness of asphalt mixture (HRN EN12697-5). Specimens of diameter of Φ100 mm and height of 60-65 mm were compacted in the laboratory according to the standard Marshall procedure (HRN EN12697-30). Asphalt specimen dimensions were determined according to the standard HRN EN 12697-29, the density of asphalt specimens according to HRN EN 12697-6 and voids in asphalt specimens according to HRN EN 12697-8; the Marshall testing was carried out according to the standard HRN EN 12697-34.

During the first part of testing 848 measurements of the stiffness modulus were carried out, at four different temperatures and on 106 specimens prepared from seven asphalt mixtures [3]. All the specimens were tested at four temperatures: +5°C, +15°C, +25°C and +35°C, with respect to the asphalt pavement temperature range in Croatia (-8°C to +38°C,) and with respect to the equipment manufacturer's recommendation (+0°C to +35°C). Four temperature measurements were selected as the optimum number for obtaining the curve of the stiffness modulus dependence on temperature. The specimens were tested in both directions and, in case the values of measured modulus did not show too large deviations, their mean value is the specimen stiffness modulus at a certain temperature. Table 1. presents the first part of the asphalt mixtures stiffness modulus testing programme.

Table 1 Stiffness modulus testing programme (first part of testing)

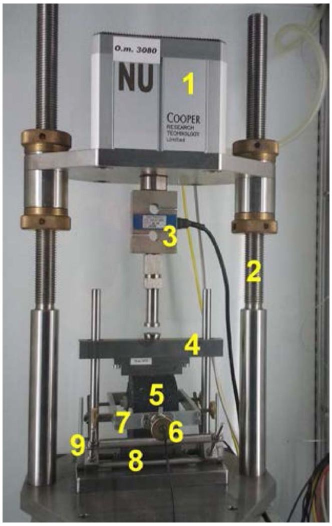
Mixture		AC11surf (1)		SMA 11 (1)		AC 16 surf		SMA 11 (2)		AC11surf (2)		AC16bin		AC22base	
Binder		PmB 45/80-65		PmB 45/80-65		BIT 50/70		PmB 45/80-65		BIT 50/70		BIT 50/70		BIT 50/70	
No. of compaction blows		2*50	2*75	2*50	2*50	2*50	2*50	2*50	2*75	2*50	2*75	2*50	2*75	2*50	2*75
Measurement temp. [°C]	**Measurement direction**	**Number of specimens**													
5; 15; 25; 35	1.	40	0	32	32	32	32	32	32	32	32	32	32	32	32
	2.	40	0	32	32	32	32	32	32	32	32	32	32	32	32

The same principle was applied to testing of four asphalt mixtures type AC 11 conducted in the second part of the research, in which the shares of bitumen and filler in asphalt mixture were varied [4]. Table 2. presents the second part of the asphalt mixtures stiffness modulus testing programme.

Table 2 Stiffness modulus testing programme (second part of testing)

Mixture		AM1	AM2/1	AM2/2	AM3
Binder		BIT 50/70	BIT 50/70	BIT 50/70	BIT 50/70
Number of compaction blows		2*50	2*50	2*50	2*50
Filler Share [%;m/m]		10,7	9,4	9,0	8,2
Bitumen share [%;m/m]		3,6	7,0	5,1	5,1
Share of voids [%;v/v]		8,2	2,0	5,0	5,3
Measurement temperature [°C]	**Measurement direction**	**Number of specimens**			
5; 15; 25; 35	1.	12	12	12	12
	2.	12	12	12	12

All the testing specimens were tested on the device presented in Figure 1. The device and testing equipment are described in detail in the standard HRN EN 12697-26, Appendix C.



1 Pneumatic load impulsator
2 Steel loading frame
3 Load transfer device
4 Top loading bar
5 Test specimen
6 Screws for adjustment of LVDT (linear variable differential transformer)
7 Bearing frame LVDT
8 Bottom loading bar
9 Claws for placement of LVDT frame

Figure 1 Measurement device for asphalt mixture stiffness modulus by application of the indirect tensile test

4 Testing results

Testing results of the first part of testing are shown in Table 3. and Figure 2. The mean values of the stiffness modulus of the tested asphalt mixtures are presented, with differences in compacting of specimens, according to temperatures of measurements. The stiffness modulus obtained on the specimens compacted with 2*75 blows, i.e. on the specimens with less voids, are greater than those of the modulus obtained for the specimens compacted with 2*50 blows. Only the results of AC 16 surf mixture at 5°C, deviate from this rule. Wearing course mixtures have lower stiffness modulus than the mixtures for the binding, base and base-wearing courses. The increase of stiffness modulus following the decrease of temperature is slower in wearing course mixtures.

Table 3 Stiffness modulus values S_m (MPa) of asphalt mixtures, with differences in specimen compaction, in relation to temperatures

Asphalt mixture, Number of compaction blows	Temperature of measurement			
	5°C	15°C	25°C	35°C
SMA 11 45/80-65 (1), 2*75	11656	6047	2640	1052
SMA 11 45/80-65 (1), 2*50	11294	5645	2512	1044
SMA 11 45/80-65 (2), 2*75	11900	5733	2615	1139
SMA 11 45/80-65 (2), 2*50	10536	5217	2150	941
AC 11 surf 45/80-65, 2*50	12945	5535	2838	1133
AC 11 surf 50/70, 2*75	15851	8153	3843	1374
AC 11 surf 50/70, 2*50	14027	7218	3336	1111
AC 16 bin 50/70, 2*75	20029	10307	4499	2082
AC 16 bin 50/70, 2*50	18266	9595	4184	1817
AC 22 base 50/70, 2*75	24519	12595	6517	2446
AC 22 base 50/70, 2*50	21159	10407	4387	1487
AC 16 surf 50/70, 2*75	23327	11684	4556	1601
AC 16 surf 50/70, 2*50	24268	11041	4270	1435

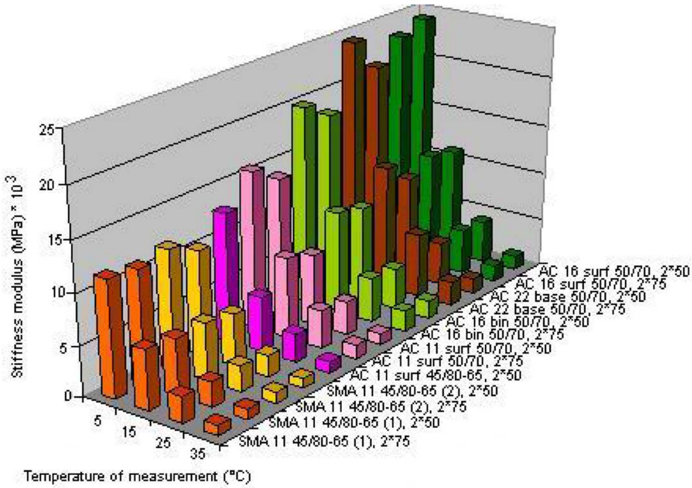


Figure 2 Asphalt mixtures stiffness modulus (MPa), with differences in compacting of specimens, at different temperatures

The stiffness modulus values of all tested mixtures decrease following temperature increase. In case of all tested mixtures the values of modulus obtained at maximal measured temperatures (35°C) are in average 91% lower that the values of modulus determined at the minimal measured temperatures (5°C). The trend of stiffness modulus decrease following temperature increase, in mixtures AC16bin, AC22base and AC16surf, differs from the one in mixtures SMA 11 and AC11surf. Table 4. and Figure 3. present results of the second part of testing.

Table 4 Composition of asphalt mixtures and average stiffness modulus at different test temperatures

Asphalt mixture	Filler share [%;m/m]	Bitumen share [%;m/m]	Share of voids [%;v/v]	Modulus (50°C) [MPa]	Modulus (150°C) [MPa]	Modulus (250°C) [MPa]	Modulus (350°C) [MPa]
AM1	10.7	3.6	8.2	15755	10059	4531	1281
AM2/1	9.4	7.0	2.0	7062	4308	1903	911
AM2/2	9.0	5.1	5.0	11990	7108	2898	857
AM3	8.2	5.1	5.3	11089	7052	2740	1060

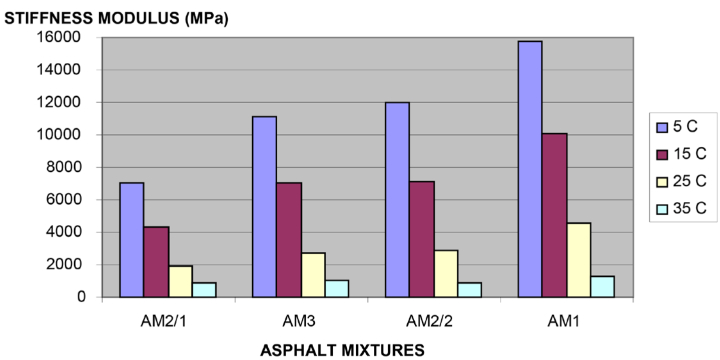


Figure 3 Graphical presentation of asphalt mixtures stiffness modulus at different temperatures

Table 4. shows the mean values of stiffness modulus of individual asphalt mixtures (AM1; AM2/1; AM2/2 and AM3) on test temperatures of 5°C; 15°C; 25°C and 35°C, including respective data on composition of filler and bitumen components and the share of voids in asphalt specimen (same materials in mixtures). The highest values of modulus, on all temperatures, are gained in mixture with the highest filler and voids share and the lowest bitumen share. The lowest values of modulus, on all temperatures, are gained in mixture with the lowest voids share and the highest bitumen share, with relatively high filler share. It can be concluded, from the results of the second part of testing, that values of stiffness modulus generally increase with increase of filler share, and with decrease of bitumen share. The graphical presentation shown below in Figure 3. indicates the trends of stiffness modulus in dependence on composition and properties of asphalt mixture at different temperatures, i.e. behaviour of asphalt at application of load within the indirect tensile impulse testing. The values of stiffness modulus of an optimal asphalt mixture (AM3) are within the medium stiffness area.

5 Conclusion

The stiffness modulus determined at four temperature values confirmed that the indirect tensile testing method enables optimisation of composition and properties of asphalt mixture. Based on the obtained data, the assumptions made during dimensioning shall be closer to the actual behaviour of asphalt pavement structures during exploitation. This will contribute to decreasing of possible deviations from actual values in calculation of stresses and deformities of individual courses due to traffic load and therefore to optimisation of procedure of structural designing of asphalt pavement structures.

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