CHANGE OF THE MECHANICAL PROPERTIES (STIFFNESS, FATIGUE) OF ASPHALTS DURING FACTORY PRODUCTION

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ABSTRACT
The European asphalt product standards coming into effect have brought the mechanical tests of asphalt, such as wheel tracking, water sensitivity, stiffness modulus and fatigue tests into prominence. The performance of said test methods are also specified in the European standards. The methods laid down in several of the test standards included are not fully developed and leave several questions unanswered. These issues also have an influence on the limit values of the performance related parameters during use and achievability of there limit values themselves, which performance in the Hungarian requirements too..
In the course of the work presented, we examined the deviation of the modulus and fatigue values during asphalt mix production from the values set during the type tests, as well as the change of said two parameters in time. We used the test method stipulated in EN 12697-26:2005, Annex C to determine the modulus and in EN 12697-24:2004+A1:2008, Annex A to determine the fatigue values. We examined several types of various bituminous concrete mixes. We determined the modulus and fatigue values during the type tests for all mixes, then repeated the tests to determine the modulus and fatigue values of the samples taken at various points in time during asphalt mix production. We analysed the change of modulus and fatigue in time, looking for correlations between the bulk density, richness factor (K), stiffness and fatigue of the tested mixes.

Keywords: mechanical properties, stiffness, fatigue, testing

1. INTRODUCTION

Hungarian road specifications on asphalt mixes are based on the European product standards. Hungarian specifications opted for the fundamental requirements of asphalt concrete mixes, this way stiffness and fatigue are requirements in Hungarian specifications pursuant to Point 5.4. of EN 13108-1:2006 [1]. Hungarian requirements on the type of asphalt concrete mixes include high modulus asphalt mixes. Their required stiffness and fatigue values are determined by the specific requirements illustrated in Table 1 [2].

Table 1: Stiffness and fatigue requirements of AC 16/22 binder (NM) asphalt mixes

Test method	Temperature, ^oC	Frequency, Hz	Requirement
		Stiffness, S	
2 PB-TR	15	10	min. 11000 MPa
4 PB-PR	20	8	min. 7000 MPa
IT-CY	20	124 μs	min. 7000 MPa
		Fatigue, ε_6	
2 PB-TR	10	25	min. 115 microstrain
4 PB-PR	20	30	min. 115 microstrain

The Hungarian specifications [2] have no stiffness or fatigue requirements for other asphalt concrete mixes, however, both stiffness and fatigue of asphalt concrete mixes made of pure crushed aggregates must be tested and their respective values recorded. The requirement values presented in Table 1 pertain to the type test of asphalt mixes, therefore, these values must be included in the type test records.

A question arose in the course of asphalt mix production, which is what the deviation rate of the stiffness and fatigue values set in the type tests changes during asphalt mix production, in other words what rate of stiffness and fatigue variance occurs during the production process compared to the stiffness and fatigue values established during the type tests in the case of mixes that are produced according to standard EN 13108-21:2006 [3] and are in conformity with Table A1 of the standard. We considered this matter important, because type tests are usually performed on mixes produced in laboratories, nonetheless, it is important for us to have a realistic picture of the performance of actually incorporated asphalt mixes.

2. TEST METHODS

We worked with four different types of asphalt mixes to realise the objective identified in the introduction. The asphalt mixes were as follows:

- Mix I. AC 22 binder (mNM) 10/40-65, the binder was modified bitumen, the aggregates fraction used was crushed basalt and dolomite (mNM: means a high modulus asphalt – NM -, produced with modified bitumen)
- Mix II. AC 22 binder (mNM) 10/40-65, the binder was modified bitumen, the aggregates fraction used was crushed dolomite, RA (reclaimed asphalt) content 10%
- Mix III. AC 22 binder (mF) 25/55-65, the binder was modified bitumen, the aggregates fraction used was only crushed andesite (mF: means an asphalt type for heavy traffic, and produced with modified bitumen)
- Mix IV. AC 32 base (F) 50/70, the binder was regular bitumen, the aggregates fraction used was crushed gravel and andesite, RA content 10% (F: means an asphalt type for heavy traffic, and produced with normal bitumen)

We took samples from the asphalt mixes at various points in time during production. Table 2 presents the sampling dates.

Table 2: Sampling dates of asphalt mixes

Asphalt mix type	Sampling date	Asphalt mix mark
Mix I.	2010.03.17 Type test	I/T
	2010.08.09	I/1
	2010.08.11	I/2
	2010.09.22	I/3
	2010.11.04	I/4
Mix II.	2010.04.27 Type test	II/T
	2010.08.25	II/1
	2010.09.02	II/2
	2010.09.29	II/3
	2010.09.30	II/4
	2011.07.13	II/5
Mix III.	2009.09.08 Type test	III/T
	2010.08.24	III/1
	2010.09.20	III/2
	2010.09.21	III/3
	2010.10.04	III/4

Mix IV.	2010.10.30 Type test	IV/T
	2010.11.02	IV/1
	2010.12.02	IV/2
	2010.12.03	IV/3

We examined the bitumen content off the asphalt mixes sampled according to Table 2 as specified in section 5.4.2.1. of EN 12697-1:2006 [4] and grading as specified in EN 12697-2:2002+A1:2008 [5]. The test results are summarised in Table 3 also indicating the requirements laid down in table A1 of standard EN 13108-21:2006 [3].

Table 3: Composition characteristics of the asphalt mixes produced

Percentage passing	Individual samples Tolerance about target composition				
	Mix I.	Mix II.	Mix III.	Mix IV.	Requirement (Large aggregate mixes)
D	-1 / +1	-6 / +0	-5 / +0	±0	+5 / -9
D/2	-9 / +6	-8 / +1	-1 / +4	-1 / +9	± 9
2 mm	-6 / +0	-3 / +3	-3 / +0	-5 / +1	± 7
0,125 mm	-3 /+1	-0 / +2	-1 /+0	-1 / +1	± 5
0,063 mm	-2,5 / +0,6	-0,9 / -1,1	-0,6 / +0	-1,2 / +0,7	± 3
Soluble binder content	- 0,3 / + 0,3	-0,2 / +0,7	-0 / +0,3	-0,1 / +0,6	± 0,6

Table 3. demonstrates that the mixes tested fulfilled the requirements of factory production control.
For characterization of the tested mix compositions we calculated the richness factor (K) [6] – which establishes a relation between the coated surface area of the aggregate and the binder content – in case of each tested mix. The richness factors of the tested mixtures are illustrated in Table 4.
Taking the asphalt mixes listed in Table 2., we used the ITCY method as specified in EN 12697-26:2005, Annex C [7] to test stiffness on Marshall specimens prepared at 20 °C by 2*50 hits, also tested fatigue using the two-point method as specified in EN 12697-24:2004+A1:2008, Annex A [8] on trapezoidal specimens at 10 °C temperature applying 25 Hz frequency, and the bulk density of the specimen according to EN 12697-6:2003+A1:2008 [9], B method (Marshall test specimens) and D method (trapezoidal test specimens).

Table 4: Mean and standard deviation of the richness factor (K) in the tested mixes

Type of mix	Mean value under production	Standard deviation,	Maximum	Minimum
Mix I.	3,08	0,18	2,92	3,26
Mix II.	3,02	0,26	2,73	3,34
Mix. III.	2,77	0,07	2,69	2,87
Mix IV.	3,00	0,22	2,81	3,27

3. TEST RESULTS

3.1. Stiffness modulus results

The modulus results of the asphalt mixes tested are illustrated in Figure 1.

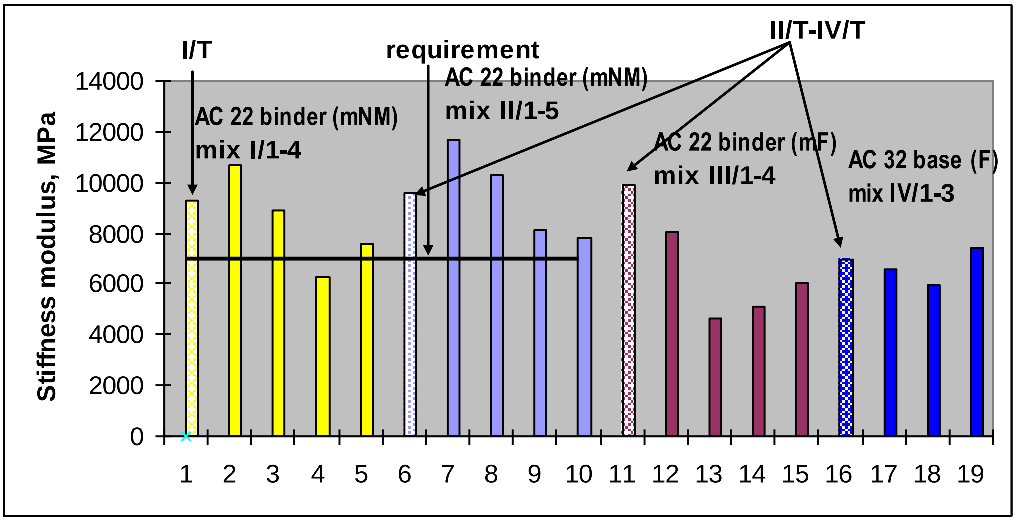

Figure 1: Modulus results of the tested asphalt mixes

Figure 1 reveals that the modulus values of the asphalt mixes produced are higher or lower than the modulus values determined in the type tests. There are also requirement values for Mix I. and Mix II. The modulus values established in the type tests meet the requirement. With the exception of one result, all the modulus values tested during factory production control also meet the requirement value.

We also examined the extent the mean of the modulus values under production approaches the values set during the type tests, and also examined the deviation. The modulus means and the deviation of the mixes tested are illustrated in Table 5.

Table 5: Mean and deviation of the modulus in the tested mixes

Type of mix	Modulus of type test, MPa	Mean value under production, MPa	Standard deviation, Mpa	Deviation % in mean of stiffness modulus
Mix I.	9257	8357	1890	22,6
Mix II.	9554	9589	1610	16,8
Mix. III.	9864	5953	1508	25,3
Mix IV.	6983	6745	645	9,6

The mean modulus of the mixes tested – with the exception of Mix III. – show a good approximation to the values set during the type test. The modulus results show a deviation of 10-25%, however, the standard deviation over the mean of the moduluses is 18.6%.

In Table 6. we give the mean values of bulk density, richness factor and stiffness modulus of tested mixes.

Table 6: Mean values of bulk density, richness factor and stiffness modulus

Type of mix	Mean value of bulk density under production, kg/m^3	Mean value of richness factor under production	Mean value of stiffness modulus under production, MPa
Mix I.	2459	3,08	8357
Mix II.	2480	3,02	9589
Mix. III.	2357	2,77	5953
Mix IV.	2355	3,00	6745

We examined the relationship between bulk density and modulus, richness factor (K) and modulus in order to establish the extent the change in the composition parameters of the asphalt mixes influences modulus values. We represented the data lines (modulus and bulk density or rather richness factor and modulus) on a diagram, and then laid trend line on it so that the R^2 would indicate the closest relationship.

The mean bulk density – modulus relationship is shown in Figure 2. The mean richness factor – modulus relationship is in Figure 3. The variation of the composition parameters indicated in the diagrams satisfied the requirements laid down in table A1 of standard EN 13108-21:2006 (see Table 3).

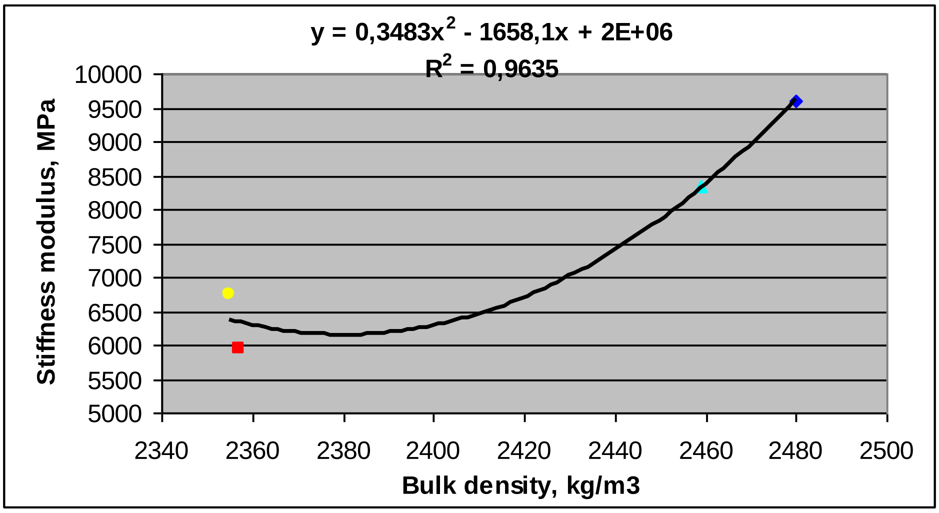

Figure 2: Bulk density – modulus relationship

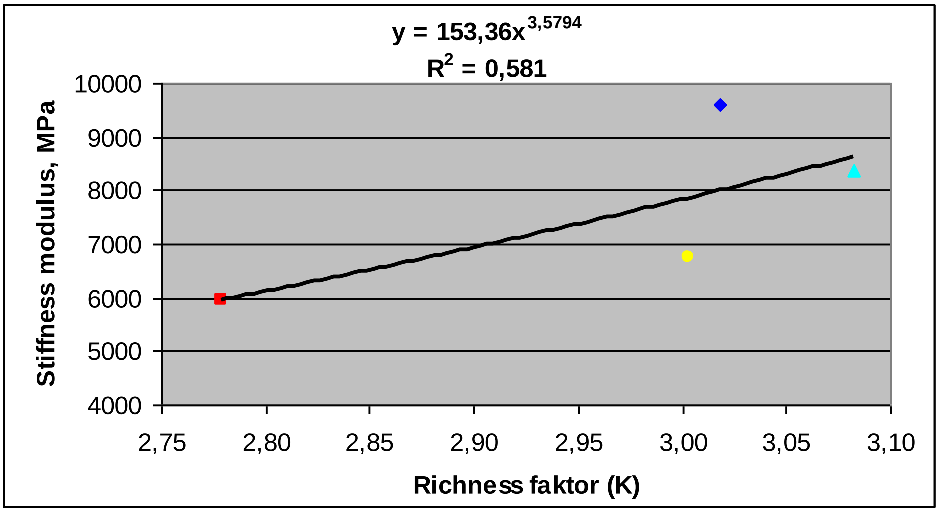

Figure 3: Richness factor (K) – modulus relationship

The figures show that there is a loose relationship between the composition parameter (richness factor) and modulus values. The bulk density and modulus values of the asphalt mixes examined show the closest relationship.

3.2. Fatigue results

The fatigue results of the asphalt mixes tested are illustrated in Figure 4.

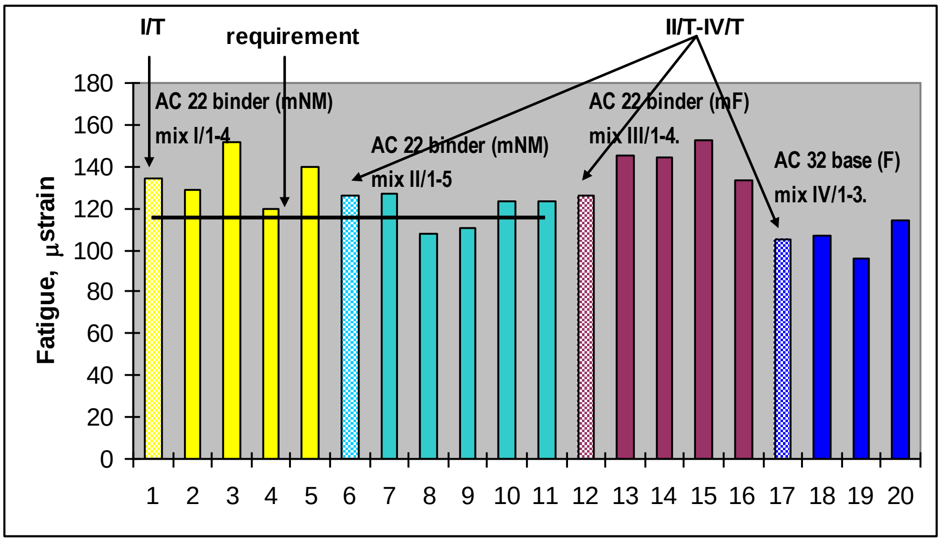

Figure 4: Fatigue results of the tested asphalt mixes

Figure 4. reveals that the fatigue results of the asphalt mixes produced are higher or lower than the fatigue values determined in the type tests. There are also requirement values for Mix I. and Mix II. The fatigue values established in the type tests meet the requirement. The fatigue values tested during factory production – with the exception of two (in the case of Mix II.) – meet the requirement.

We also examined the extent the mean of the fatigue values under production approaches the values set during the type tests, and also examined the deviation. The fatigue means and the deviation of the mixes tested are illustrated in Table 7.

Table 7: Mean and deviation of fatigue in the tested mixes

Type of mix	Fatigue of type test, μstrain	Mean value under production, μstrain	Standard deviation, μstrain	Deviation % in mean of fatigue
Mix I.	134	135	14	10,2
Mix II.	126	118	8	7,1
Mix. III.	126	144	8	5,7
Mix IV.	105	106	7	7,0

The mean fatigue of the mixes tested – with the exception of Mix III. – show a good approximation to the values set during the type test. The fatigue results show a deviation of 6-10%, however, the standard deviation over the mean of fatigue is 7.5 %.
In Table 8. we give the mean values of richness factor and fatigue of tested mixes.

Table 8: Mean values of richness factor and fatigue

Type of mix	Mean value of richness factor under production	Mean value fatigue under production, MPa
Mix I.	3,08	135
Mix II.	3,02	118
Mix. III.	2,77	144
Mix IV.	3,00	106

We examined the relationship richness factor and fatigue in order to establish the extent the change in the composition parameters of the asphalt mixes influences fatigue values. We represented the data lines on a diagram, then laid trend line on it so that the R^2 would indicate the closest relationship.
The mean richness factor – fatigue relationship is shown in Figure 5. The variation of the composition parameters indicated in the diagrams satisfied the requirements laid down in table A1 of standard EN 13108-21:2006] (see Table 3).

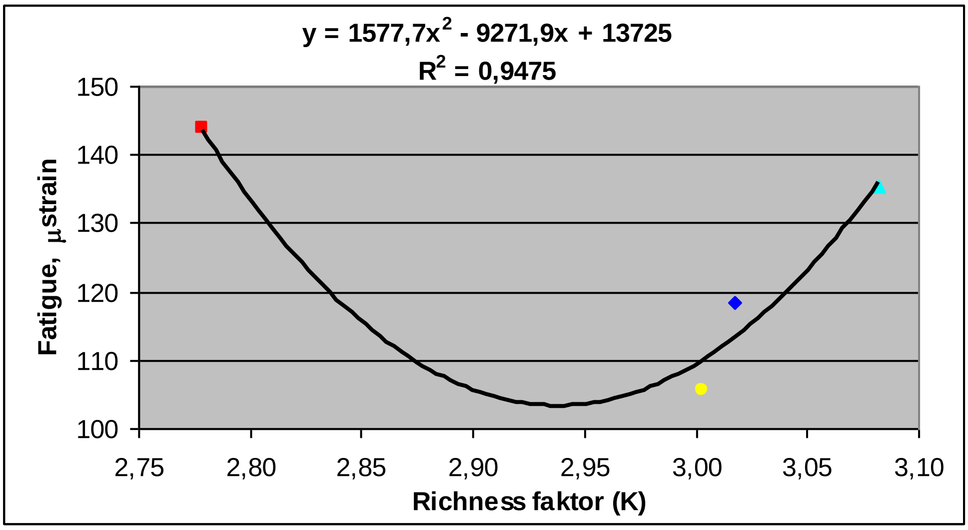

Figure 5: Richness factor – fatigue relationship

The Figure 5 shows that there is a close relationship between the composition parameters (richness factor) and fatigue values.

4. SUMMARY, CONCLUSIONS

We took asphalt samples at various points in time of the production process of asphalt mixes of diverse composition in the course of the work. We examined the stiffness modulus, fatigue, composition and bulk density of the asphalt mixes. We compared the modulus and fatigue values of the asphalt mixes produced with the modulus and fatigue values established during the laboratory type tests. We sought relationship between the composition parameters (richness factor) of the examined asphalt mixes and stiffness modulus and fatigue values.
The summary of our findings are as follows:

- The production fluctuations of the asphalt mixes tested satisfied the factory production control [3] requirements.
- The modulus and fatigue mean values of the produced asphalt mixes tested showed a good approximation to the modulus and fatigue values determined during the type tests, therefore, the modulus and fatigue values stipulated in the type test appropriately characterize the modulus and fatigue values of the asphalt mixes produced. For that reason, it is not necessary frequently to apply the lengthy and costly tests to control modulus and fatigue values during production.
- The modulus values of the asphalt mixes produced show a higher deviation than the fatigue values. It indicates that the modulus values are more sensitive to fluctuations in production than fatigue values.
- There is a weak relation between the richness factor of the asphalt mixes produced and the stiffness modulus values tested. The bulk density variation of the asphalt mixes tested has a more profound impact on the modulus values than the variation of composition parameters. There is a close relation between the richness factor of the asphalt mixes produced and the fatigue values tested.

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