CETRA 2014

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

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CETRA 2014
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

TITLE
Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, April 2014

COPIES
400

Zagreb, April 2014.

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3rd International Conference on Road and Rail Infrastructures – CETRA 2014
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THE IMPACT OF COMPACTION ENERGY ON THE PROPERTIES OF ASPHALT LAYERS

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Abstract

At an installation of the hot mix asphalt on a construction site, it is necessary to achieve the designed quality of the built asphalt layer. On the quality of the built asphalt layer affect the temperature of the asphalt mix, the quality of a bearing layer, external weather conditions and energy invested during the installation of hot mix asphalt. Laboratory tests aimed to determine the dependence of the invested variable compaction energy on asphalt mix AC 8 surf 50/70 AG1 M4 and the achieved density of the test specimens in the laboratory conditions. The designed asphalt mix was made up in the laboratory of stone fractions of igneous origin, stone dust of dolomite origin and bitumen 50/70. The obtained results indicate that the invested compaction energy significantly affects on the achieved quality of the laboratory made asphalt specimens.

Keywords: hot mix asphalt, quality of the built asphalt layer, compaction energy.

1 Introduction

Asphalt layers are the elements of a pavement structure that take traffic load and pass it on the bearing layer structures, and are made by an installation of hot asphalt mixes, a three-component or multi-component composite [1] of the composition defined by volume shares of grained mineral mixture, bitumen and air in the voids. Asphalt mixes should contain 3-5% of voids [2], and any further deviation leads to the appearance of permanent deformations. Voids are the most usually measured volumetric feature of hot asphalt mixes because their share in the total asphalt mix affects on the stability and persistence of the same [3-6]. The share of voids (air) of 5-8%, or less than 3%, results in the formation of cracks and the emergence of tracks on asphalt pavements [7-8] and the inability of spreading asphalt and additional densification due to the traffic load. When installing asphalt mix, it is necessary to achieve the designed densities and porosity reduction in the resulting layer because any increase of voids by 1% (more than 6-7%) leads to a 10% reduction in the designed durability of asphalt pavement [9]. The density of asphalt layers is one of the most important factors that affects the durability of the asphalt pavement. Compaction of hot mix asphalt reduces the proportion of voids (air) and increases the unit weight of the compacted mix. According to studies [10-16], compaction is probably the most important activity in the construction of each of the layers of the pavement structure, and especially of asphalt layers. Well compacted embedded asphalt layers provide some waterproofing, strength and resistance to the emergence of tracks and prevent excessive aging, i.e. oxidation of bitumen. Workability of the asphalt mix depends on the composition of bituminous mix, the quality of bitumen and its viscosity, as well as on the temperature at which the installation is done. Hot asphalt mixes are designed by classical methods (Marshall, Hveem, Duriez or Approximate) and by methods of recent approaches (the Superpave method and harmonized European standards). Compaction of laboratory specimens of bituminous mixes is done by compactors, such as the Marshall compactor, the Hveem stabilometer or the Superpave gyratory compactor. This study applied the Marshall method of compacting designed hot mix asphalt. Designing hot mix asphalt by the Marshall method is linked to the thirties of the last century, the author of which is Bruce Marshall. They were adopted with the aim of designing an optimal gradation of aggregates, fillers and bituminous binder for asphalt pavement curtains resistant to permanent deformations. Today, the Marshall method is used in 38 countries around the world [19]. Asphalt mixes designed for installation into pavement structures for higher traffic loads contain a greater proportion of larger mineral fractions and during the installation require greater invested compaction energy. Mixes that are built into the structures of lower traffic loads contain a greater proportion of fractions of finer granulation, and are thus easily compacted. The American standard AASHTO (American Association of State Highway and Transportation Officials Standards) prescribes compaction criteria for asphalt mix specimens depending on traffic load of the pavement structure (Table 1), while the Croatian and European standards prescribe compaction criteria by the Marshall compactor based on 50 strokes on each side of the asphalt mix specimen [20].

Table 1 The Marshall method designed criteria (Asphalt Institute, Lexington, KY,1979.) [19]

Criterion	Low traffic $<10^4$ ESALs		Medium traffic 10^4-10^6 ESALs		Heavy traffic $>10^6$ ESALs	
	Min	Max	Min	Max	Min	Max
Compaction (number of strokes on each side of the specimen)	35		50		75	
Stability (min)	2 224 N		3 336 N		6 672 N	
% Voids (air)	3	5	3	5	3	5
ESALs – equivalent single axle load (equivalent to single-shaft load)						

The problem of density of asphalt mix before and after compaction is the subject of many studies. Neubauer [21] studied the effect of compaction temperature of hot mix asphalt onto volume changes, and came to the conclusion that the density decreases from the centre to the surface, i.e. to the bottom or the top of the asphalt specimens in the mold. Raab, in her researches, [22] found an unbalanced distribution of voids (air) immediately after compaction, where the asphalt specimen had a lower content of voids (air) in the middle and the upper surface than on the edges (edge lines) and in the lower parts. Since, during compaction, bitumen in the mixture acts as a lubricant, and with its share leads to a reduction of friction between the grains of the mineral mix, these are the investigated and the quantitative relationships of the compaction level and the voids filled with bituminous binder, wherein the results obtained indicate that the reduction of voids filled with bitumen binder for 4-12 % will result in the reduction of stiffness modulus by 55 % [23]. In this paper, the authors examined in the laboratory conditions the impact of variable compaction energy, at constant compaction temperature, of asphalt specimens of hot mix asphalt AC 8 surf 50/70 AG1 M4.

2 Experimental part

Laboratory tests include making hot mix asphalt AC 8 surf 50/70 AG1 M4 prepared under controlled conditions. Asphalt is the mixture of a fixed gradation of mineral mixture, the share of bitumen and the temperature at which compaction of test specimens is done (155°C). In order to determine in the laboratory the impact of the changing compaction energy on the properties of the test specimens of asphalt samples, it is carried out the preparation of specimens exposed to a variable number of strokes in the Marshall compactor. In the paving laboratory, the properties of asphalt mixtures specimens are tested according to HRN EN 13108-1 [24] made from stone fractions 0/2, 2/4 and 4/8 mm of volcanic origin from the Vetovo quarry, stone dust category label KB-I from the Veličanka quarry and road bitumen 50/70, MOL producer, the Republic of Hungary.

2.1 Composition of designed asphalt mix

Designed asphalt mixture contains in its composition stone fractions from the Vetovo quarry (an eruptive material of silicate composition) and stone dust from the Veličanka quarry (carbonate composition sediment). Table 2. shows the shares of certain fractions in the designed mineral mixture and the average densities determined in accordance with the standards HRN EN 1097-7 and HRN EN 1097-6 [25, 26].
Table 3. shows the gradation of the constituent mineral fractions determined according to the standard HRN EN 12697-2 [27].

Table 2 Densities and shares of stone fractions in the overall mineral mixture

Stone materials	Fraction marks	Share in the mineral mixture [%(m/m)]	Density [t/m³]
"Veličanka"	KB	7.4	2.8
"Vetovo"	0/2	31.2	2.88
"Vetovo"	2/4	23.8	2.9
"Vetovo"	4/8	37.6	2.8

Table 3 Gradation of used mineral fractions and filler

Opening of the sieve [mm]	Passage through the sieve [%(m/m)]			
	Stone dust	Vetovo quarry	Vetovo quarry	Vetovo quarry
		0-2	2-4	4-8
0.063	70.1	4.1	1.8	1.3
0.25	100	20.5	2.4	1.7
1	100	64.0	3.7	1.9
2	100	95.6	12.1	2.1
4	100	100	92.7	7.5
8	100	100	100	94.6
11.2	100	100	100	100
16	100	100	100	100
22.4	100	100	100	100
31.5	100	100	100	100

Used binder is a road bitumen 50/70, by MOL producer, from the Republic of Hungary. Standard properties of the road bitumen include density ρ_B = 1.012 g/cm^3, the softening point PK = 50.3°C and penetration PEN = 57 1/10 mm, tested according to the standards HRN EN 1425:2012 and HRN EN 1426:2008 [28, 29].

2.2 Designing the composition of asphalt mix

Gradation of the designed asphalt mixture is shown in Figure 1., while the soluble proportion of road bitumen is tested according to HRN EN 12697-1 [30] and adopted in the amount of 5.9%.

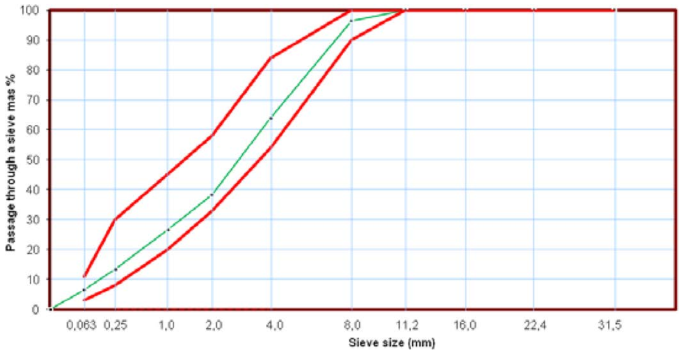

Figure 1 Gradation of the designed asphalt mixture

For each group of asphalt mix, the three test specimens were made according to the standard compaction procedure on the Marshall compactor with the falling hammer. The specimens, according to Annex C of the standard HRN EN 13108-20 [20], are compacted under variable number of strokes. Table 4. shows the conditions of preparation of test specimens of asphalt specimens. The compaction of the asphalt mixture is done by 1-70 strokes (on each side), where the number of strokes subsequently increases by 10 for each subsequent group (Group 2-8). Figure 2. shows the specimens compacted with 10, 30 and 70 strokes, i.e. the samples of the Group 2, Group 4 and Group 8.

Table 4 Conditions for preparing asphalt specimens

Test sizes	Unit measures	Gr. 1.	Gr. 2.	Gr. 3.	Gr. 4.	Gr. 5.	Gr. 6.	Gr. 7.	Gr. 8.
Hammer mass	g	4.560	4.560	4.560	4.560	4.560	4.560	4.560	4.560
Height of falling hammer	mm	460	460	460	460	460	460	460	460
Number of layers	–	1	1	1	1	1	1	1	1
Number of strokes per layer	–	2×1	2×10	2×20	2×30	2×40	2×50	2×60	2×70
The diameter of the specimens after compaction	mm	101.2	101.5	101.6	101.4	101.5	101.6	101.5	101.4
The height of the sample aft. compaction	mm	80.3	68.3	65.4	64.3	63.0	62.5	61.9	61.9

Figure 2 Laboratory asphalt specimens

After cooling asphalt specimens, the following properties were determined on the same:
- the density of the asphalt specimens according to the standard HRN EN 12697-6 [31],
- the density of asphalt mixture according to the standard HRN EN 12697-5 [32],
- the share of voids according to the standard HRN EN 12697-8 [33],
- voids filled with bitumen according to the standard HRN EN 12697-8 [33].

2.3 Achieved results

Table 5. presents the results of the performed laboratory tests. From Table 5., it is evident that the densities of asphalt specimens fall significantly with the decrease in the number of strokes at which compaction is done. The reduction of the number of strokes during compaction leads to the growth of share of voids in the test specimens.

Table 5 The results achieved after compaction in the Marshall compactor

Group	Density [kg/m³]		Share of voids [%]	The thickness of the specimen [mm]	The diameter of the mold [mm]
	Marshall	Asphalt mixture			
Group 1.	2.120	2.566	17.4	80.3	101.2
Group 2.	2.316	2.566	9.7	68.3	101.5
Group 3.	2.397	2.566	6.6	65.4	101.6
Group 4.	2.433	2.566	5.2	64.3	101.4
Group 5.	2.487	2.566	3.1	63.0	101.5
Group 6.	2.497	2.566	2.7	62.5	101.6
Group 7.	2.509	2.566	2.2	61.9	101.5
Group 8.	2.511	2.566	2.1	61.9	101.4

3 The dependence of the results achieved

The further study shows the dependences of variable compaction energy in the Marshal compactor and generated voids in asphalt specimens, the altitude of test specimens, as well as the densities of asphalt specimens.

3.1 Dependence of voids and compaction energy

Figure 3. shows the ratio of voids in asphalt specimens and variable compaction energy in the Marshall compactor. By applying the obtained values onto the coordinate axes, it can be seen exponential relationship between the observed values and, consequently, is analyzed the link model which is as follows:

$$U=ae^{bx} \quad (1)$$

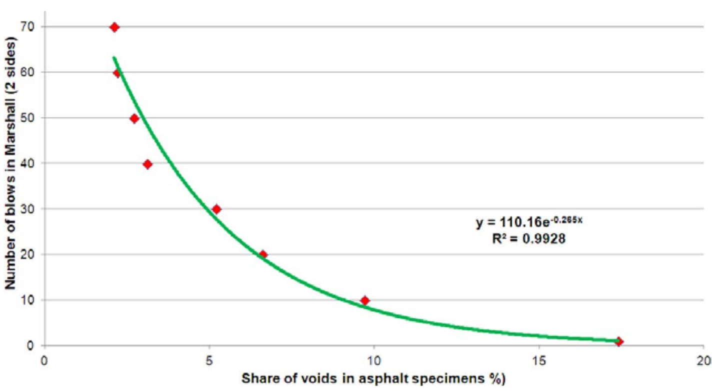

Figure 3 The ratio of the voids and the variable compaction energy

Figure 3. shows a very high coefficient of determination, $R^2 = 0.9928$, which indicates to the dependence of realized values of share of voids and effects of variable compaction energy in laboratory conditions.

3.2 Dependence of variable compaction energy and the altitude of asphalt specimens

Figure 4. shows the dependence of variable compaction energy and the altitude of asphalt specimens. The values obtained are applied on the axes of the coordinate system and is analyzed the link model which is as follows:

$$V=ax^b \quad (2)$$

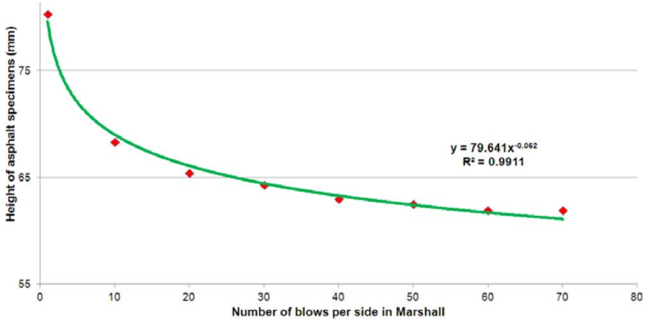

Figure 4 The ratio of compaction energy and the altitude of asphalt specimens

In Figure 4., it is evident that due to the growth of compaction energy, there follows a decrease in the altitude of test specimens and higher densities. It is observed a very high coefficient of determination, $R^2 = 0.9911$, which indicates that the mathematical notation of the referred dependence realistically describes the observed values.

3.3 Dependence of variable energy and densities of test specimens

Figure 5. shows the dependence of densities of asphalt specimens and variable compaction energy in laboratory conditions. The values obtained are applied on the axes of the coordinate system and is analyzed the following mathematical model:

$$G_{AU}=ax^b \quad (3)$$

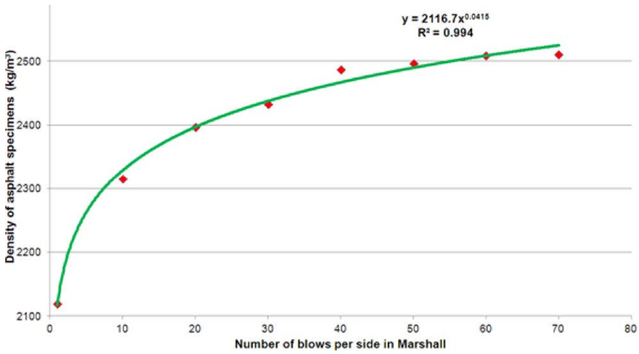

Figure 5 The ratio of variable energy and densities of asphalt specimens

The shown dependence in Figure 5. suggests to the conclusion that the increase of the invested compaction energy leads to higher densities of asphalt specimens. The coefficient of determination, R^2, of the displayed dependence amounts to 0.994 and indicates that the mathematical notation realistically describes the observed properties. Correlations of the observed properties as well as forms and the strengths of bonds for obtained results are shown in Table 6.

Table 6 Correlations of properties

Property of test specimen	Variable	Link form	Coefficients		The coefficient of determination
			a	b	R^2
Voids and energy compaction	(x) – voids	$U=ae^{bx}$	110.16	-0.265	0.9928
Energy and altitude of test specimen	(x) – the number of strokes in Marshall compactor	$V=ax^b$	79.641	-0.062	0.9911
Energy and densities	(x) – the number of strokes in Marshall compactor	$G_{AU}=ax^b$	2,116.7	0.0415	0.994

4 Conclusion

The quality of the built asphalt layer is significantly affected by invested compaction energy during installation. It is necessary to perform the installation of bituminous mixture at the designed temperature in dependence relation to the composition of the asphalt mixture. The density of the asphalt layer is defined as the weight of the mixture in a given volume. In the process of compaction, the volume of the layer reduces which results in the reduction of share of voids in the asphalt layer. Initial compaction has a far greater impact on the proportion of share of voids in relation to a further increase in compaction energy. It is also evident that the altitude of test specimens is reduced by 22.9% between the specimens compacted with 2x70 strokes (Group 8) and the specimens compacted with 2x1 strokes (Group 1). The differences in densities of the test specimens between the Group 8 and the Group 1 were 18.4%. In conclusion, the timely compaction and invested energy both prolong the durability of the built asphalt layer with minimal occurrence of deformations during the designed period of exploitation.

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