CETRA2016 23–25 May 2016, Šibenik, Croatia
4th International Conference on Road and Rail Infrastructure

STUDY OF COMPACTABILITY MODELS DESCRIBING ASPHALT SPECIMEN COMPACTION WITH GYRATORY AND WITH IMPACT COMPACTOR

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Abstract

The service life of pavement surface courses is highly dependent on the construction process. A large number of parameters have to be controlled and kept at optimum during the laying and compaction process. The compactability of asphalt mix is the most important feature at the time of paving. Proper compaction of asphalt layer ensures that the pavement can achieve the planned service life, the bearing capacity and the resistance to low and high temperatures. In this study, the compactability determined by the gyratory and impact compactor was investigated. The standardized model as described in the European standard EN 12697-10 for the compaction propagation was evaluated with the data obtained from the tests performed on five different asphalt mixtures. Past research showed that the 'standardized model' that is currently used for the impact compactor does not describe the compaction process appropriately. In a published article three new solutions were proposed. With present study we tried to find out if the new proposed models can be used to properly describe compactability of asphalt specimen determined with gyratory compactor.

Keywords: compactability, gyratory compactor, impact compactor, model

1 Introduction

Produced asphalt is non compacted mixture of stone aggregate in a binder matrix. Asphalt mix must be compacted according to certain standards to construct a sustainable pavement. Compaction means reduction in the volume of the mixture of hot asphalt binder, aggregates, and filler materials to form the required dense mass. Construction of asphalt pavements takes advantage of the direct and indirect compacting forces, exerted by rollers passing over the loose mix to produce dense layers of structurally durable material [1]. It was published that more than 80 % of premature failures of asphalt pavements are related to insufficient compaction [2, 3]. With decreasing of voids in the matrix, the material becomes less susceptible to moisture penetration [4, 5].

Compactability of the asphalt pavement can be defined as the ease with which the material can be compacted [4]. The most important factors that influence on the process of compaction are: materials used in the asphalt mixture, environmental variables (temperature, wind, and humidity), method for compaction, compaction temperature [6, 7].

Many studies were preformed to evaluate correlation between compaction and asphalt properties [8-12].

In this study we followed the procedures described in European standard EN 12697 – 10 [13] where three laboratory test methods for obtaining compactability are described: impact compaction, gyrator compaction and vibratory compaction. From previous studies it was found out that the model for impact compaction in the standard can be improved [14, 15]. It was proposed that 'standardized model' presented with eqn (1) should be replaced with 'supplemented model' presented with eqn (2):

$$\frac{1}{t(E)}=\frac{1}{t_\infty}-\left[\frac{1}{t_\infty}-\frac{1}{t_0}\right]*e^{\frac{-E}{T}} \tag{1}$$

$$\frac{1}{h(E)}=\frac{1}{h_\infty}-\left[\frac{1}{h_\infty}-\frac{1}{h_0}\right]*e^{\frac{-E}{T_1}}+F*e^{\frac{-E}{T_2}} \tag{2}$$

Where:
$t(E)$ – thickness of the specimen compacted at compaction energy E;
t_∞ – is the calculated minimum achievable thickness of the specimen;
t_0 – is the calculated initial thickness of the specimen;
E – is the compaction energy;
T – is the compaction resistance.

It was proposed that in the case when we are not able to use the appropriate software to calculate more demanding mathematical models, exclusion of first 30 data, is a proper choice [15].

2 Experimental details

Encouraged with the results of our previous studies [14, 15], we tried to find out if standardized model describing gyrator compaction can also be improved. We investigated if the proposed mathematical model for impact compaction was acceptable for the obtained experimental data. At gyrator compaction bituminous mixture is contained within a cylindrical mould limited by inserts and kept at a constant temperature within specified tolerances throughout the whole duration of the test [16].
Compaction is achieved by the simultaneous action of a low static compression, and of the shearing action resulting from the motion of the axis of the sample which generates a conical surface of revolution, of apex O and of 2 ϕ angle at the apex, while the ends of the test piece should ideally remain perpendicular to the axis of the conical surface as shown in Figure 1 [16].

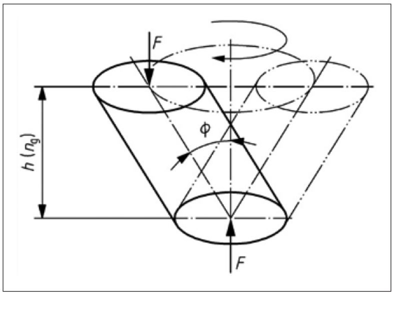

Figure 1 Sample motion diagram at gyrator compaction

2.1 Materials

Five different asphalt mixtures were collected from asphalt producers. Three different asphalt concrete samples (AC 8 surf, AC 16 surf and AC 32 base containing B 50/70 bitumen) and two different stone mastic samples (SMA 8 surf and SMA 8 surf containing PmB as binder and steel slag as stone aggregate) were tested.

2.2 Experimental design and conditions

Each sample was compacted in two moulds with diameters 150.0 mm and 100.0 mm. For each mould two different quantities of material were prepared: one for expected final height of specimen 100 mm and second for expected final height of specimen 150 mm. So for each type of asphalt 4 different dimensions of specimen were prepared. The following compaction conditions were set: target gyrations (100), speed: 30 rev/min, angle: 0,820 degrees and stress: 600 kPa. For comparison Marshal specimen with impact compactor were prepared. The compaction temperatures were for all samples set according to EN 12697-35.

2.3 Experimental results

Samples were compacted in random order. After cooling we measured final height and density for each specimen. Final densities of samples are presented in Table 1.

Table 1 Densities of samples after 100 gyrations, where h is expected height of specimen and fi is diameter of the mould.

Dimension of sample [mm]	**SMA 11** [Mg/m^3]	**SMA 8** [Mg/m^3]	**AC 16** [Mg/m^3]	**AC 8** [Mg/m^3]	**AC 32** [Mg/m^3]
fi100, h=150	**2.916**	2.801	2.460	2.472	2.474
fi150, h=150	2.891	2.825	2.527	2.450	2.518
fi100, h=100	2.878	2.838	2.547	2.532	2.546
fi150, h=100	2.893	**2.840**	**2.551**	**2.534**	**2.563**
Marshall specimen	2.836	2.839	2.503	2.497	2.502

From Table 1 it can be seen that for almost all types of asphalt the densest was sample with diameter 150 mm and final thickness 100 mm. Only exception was SMA 11 where the densest was sample with diameter 100 mm and final thickness 150 mm, but varieties between densities of samples for both SMA mixtures are small.

3 Results

3.1 Compactability according to the standard

First compactability according to the standard EN 12697-10 was calculated. The ‘standardized model’ is presented with eqn 3.

$$\upsilon(ng) = \upsilon(1) - (K \cdot \ln ng) \tag{3}$$

Where:
υ (ng) – void content for a number of gyration ng, expressed in percent (%);
υ (1) – is the calculated void content for one gyration;
K – is the compactability (method using a gyratory compactor);
ng – is the number of gyrations.

From Table 2 it can be seen that calculated compactabilities K have very stochastic values. It can be seen that the standard deviation over different types of asphalt mixtures compacted in the same mould is on average smaller than standard deviation for a particular asphalt mixture compacted in the moulds of different dimensions. From results in Table 2 it can be concluded that compactabilities K calculated according to the standard EN 12697-10 cannot be used to distinguish between different types of asphalt.

Table 2 Compactability K according to the standard EN 12697-10.

Dimension of sample [mm]	SMA 11 K	SMA 8 K	AC 16 K	AC 8 K	AC 32 K	Standard deviation over different types of asphalt mixture
fi100, h=150	4.00	3.83	3.12	3.73	3.22	**0.39**
fi150, h=150	3.66	3.58	3.39	3.82	3.32	**0.20**
fi100, h=100	4.14	4.35	4.22	4.02	4.25	**0.12**
fi150, h=100	3.86	3.59	3.74	3.40	3.85	**0.19**
Standard deviation over different mould dimensions	**0.21**	**0.36**	**0.47**	**0.26**	**0.48**	

3.2 Alternative model

Due to the fact that height of the specimen is automatically obtained from apparatus during compaction process the first 'simple' model containing height of specimen as factor was tested. According to standard the height of specimen after 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, and 100 gyrations shall be obtained from apparatus. With altogether 20 experimental points variety of models can be built. First simple alternative model was tested (eqn 4).

$$\ln t = A - \left(B \cdot \ln ng\right) \tag{4}$$

Where:

t – height of the specimen for a number of gyration ng, expressed in mm;
A – factor related to height of the specimen for one gyration;
B – alternative compactability;
ng – number of gyrations.

For comparison between the 'standardized model' and the 'alternative model' correlation coefficients were gathered in Tables 3 and 4. From Tables 3 and 4 it can be seen that both models are good and correlation coefficients are almost equal. Small difference can be found only for both SMA mixtures, where 'alternative model' works a bit better. Both models gave the lowest correlation coefficients for AC, however for this mixture standard model works a bit better.

Table 3 Correlation coefficients between directly measured heights of specimen and heights of specimen calculated according to 'standardized model' (eqn 3).

Dimension of sample [mm]	SMA 11 r^2	SMA 8 r^2	AC 16 r^2	AC 8 r^2	AC 32 r^2	Average for different types of asphalt
fi100, h=150	0.9989	0.9983	0.9995	0.9988	0.9992	0.9990
fi150, h=150	0.9981	0.9983	0.9985	0.9998	0.9991	0.9987
fi100, h=100	0.9992	0.9993	0.9996	0.9942	0.9992	0.9983
fi150, h=100	0.9964	0.9986	0.9995	0.9950	0.9995	0.9978
Average for different mould dimensions	0.9981	0.9986	0.9993	0.9969	0.9993	

Table 4 Correlation coefficients between directly measured heights of specimen and heights of specimen calculated according to 'alternative model' (eqn 4).

Dimension of sample [mm]	SMA 11 r^2	SMA 8 r^2	AC 16 r^2	AC 8 r^2	AC 32 r^2	Average for different types of asphalt
fi100, h=150	0.9997	0.9994	0.9996	0.9978	0.9987	0.9990
fi150, h=150	0.9990	0.9993	0.9992	0.9996	0.9998	0.9994
fi100, h=100	0.9998	0.9992	0.9990	0.9915	0.9993	0.9978
fi150, h=100	0.9979	0.9992	0.9989	0.9936	0.9993	0.9978
Average for different dimensions	0.9991	0.9993	0.9992	0.9956	0.9993	

3.3 Model proposed for impact compactor

It was found out that the 'standardized model' for impact compactor (eqn 1) is not appropriate even for impact compactor [14, 15], when all data is used. Consequently in this study a standardized model proposed for impact compactor was used (eqn 1), but according to experience from previous studies [14, 15], the data of the first 30 records on the specimen height were excluded from the calculation. Correlation coefficients between directly measured heights and heights of specimen calculated according to the model (eqn 1) are gathered in Table 5.

Table 5 Correlation coefficients between directly measured heights of specimen and calculated heights of specimen according to model for impact compactor (eqn 1) with exclusion of the first 30 records.

Dimension of sample [mm]	SMA 11 r^2	SMA 8 r^2	AC 16 r^2	AC 8 r^2	AC 32 r^2	Average for different types of asphalt
fi100. h=150	0.9995	1.0000	0.9994	0.9994	0.9994	0.9995
fi150. h=150	0.9998	0.9994	0.9991	0.9997	0.9996	0.9995
fi100. h=100	0.9993	0.9990	0.9995	0.9985	0.9992	0.9991
fi150. h=100	0.9995	0.9988	0.9996	0.9971	0.9993	0.9988
Average for different dimensions	0.9995	0.9993	0.9994	0.9987	0.9994	

From Table 5 it can be seen that model proposed for impact compactor works well also for gyratory compactor. Correlation coefficients are even higher than for 'standardized model' (Table 3). In Table 6 compactabilities T calculated according to the model for impact compactor (eqn 1) with exclusion of the first 30 records [15] are presented. From Table 6 it can be seen that calculated compactabilities T have less stochastic values than compactabilities K in Table 2.

Table 6 Compactability T calculated according to the model for impact compactor (eqn 1) with exclusion of the first 30 records.

Dimension of sample [mm]	SMA 11 T	SMA 8 T	AC 16 T	AC 8 T	AC 32 T	Standard deviation over different types of asphalt mixture
fi100. h=150	56.05	60.06	59.42	44.05	42.86	8.39
fi150. h=150	54.59	59.25	55.66	53.62	66.50	5.25
fi100. h=100	65.22	48.96	47.63	36.51	54.83	10.51
fi150. h=100	48.40	51.34	50.56	31.04	54.54	9.29
Standard deviation between different dimensions	6.95	5.58	5.25	9.79	9.65	

4 Conclusions

In the European standard EN 12697 – 10 are described methods to determine the compactability of the asphalt mixtures. In previous studies the compaction by impact compaction was evaluated [15] and some improvements were proposed. With this study compaction by gyratory compactor was evaluated.

Five different asphalt concrete mixtures were tested. From obtained result for different types of asphalt we found out that Compactabilities K calculated according to the standard EN 12697-10 cannot be used to distinguish between different types of asphalt. One solution for this problem is to exactly prescribe dimension of sample in the standard EN 12697-10. We propose that diameter of mould should be specified and final height of specimen should be in clearly defined range similarly as it is prescribed for impact compactor. The other solution is to use alternative model. It was found out that even simple model (eqn 4) could be more suitable for some asphalt mixtures than standardized model. The most logical results were obtained with model proposed for impact compactor [15].

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