Asphalt mixture performance and testing

Can be compactability, determined by impact and gyratory compactor, described with one single model?

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Abstract

This paper presents new uniform model for compaction propagation generated by impact and gyratory compactor. Currently European standard EN 12697-10 defines two different models, independently for an impact compactor and for a gyratory compactor. There is no correlation between those two standardised models. In our previous studies it has already been established that the model defined in EN 12697-10 for impact compactor does not appropriately describe the compaction process. The prediction of the compaction, especially at the end of the compaction process, differs from the experimental results of the compaction tests, which was confirmed on several different asphalt mixtures. In order to achieve improved predictions, new research was performed on AC asphalt mixture of different gradations. Comparative compaction was performed on gyratory compaction device according to EN 12697-31 and impact compaction device (Marshal Compactor) according to EN 12697-30. Based on the results of these tests an improved model for the compaction propagation is proposed. It consists of two parts and results in good fitting of experimental data for either compaction process. The improved new model may be universal for both methods of compaction and may offer a supplementary solution to the one currently standardised and specified in EN 12697-10.

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1. INTODUCTION

Asphalt mixtures are mainly produced in asphalt plants. Quality of produced asphalt mixtures depends on quality of constituents and of quality of mixing process. Produced asphalt mixtures are then transported to construction site. Asphalt mixture must be delivered to construction site warm enough to be compactable. Paving and compaction of asphalt pavement must be done while the asphalt is sufficiently warm. Quality of laid asphalt pavement depends on quality of asphalt mixture and of quality of compaction process. So compaction is one of the most important factors that effect on properties of the road in the lifetime. Reason for more than 80% of premature failures is related to inadequate compaction [1, 2]. When asphalt layer is properly compacted, fewer particles are shifting under the loading. Proper compacting provides also optimal number of contact points between the particles, so forces in the contact points between the particles are decreased.

For simulation field and laboratory compaction processes several models can be used. Some models have real mechanical background; other models are representing good fit with experimental data. At present, the European standard EN 12697-10 defines three completely different models, independently for impact, gyratory and vibratory laboratory compactors. Results of these models are parameters (C, T, K, and k) that should represent compactability of asphalt mixture. Since the models are different and the parameters obtained by different compaction methods are not of the same order of magnitude, it is difficult to compare different methods of compaction. In our previous study [3], it has already been established that the model defined for impact compactor does not appropriately describe the compaction process. In previous study [3], we proposed some models, which fit experimental data better than standardised model. Currant research was performed on AC and SMA asphalt mixtures of different gradations. Compaction was performed with gyratory compaction device according to EN 12697-31. It was expected that model that works the best for describing compaction with impact compactor is also performing well for gyratory compaction [4].

2. EXPERIMENTAL DATA AND MODELING

2.1. Comparison between standardised model and supplemented model

First part of experimental work with impact compactor was performed in one private company and results have already been explained in detail [3]. Second part of experimental work with gyratory compactor was performed in public institute and results have also already been published [4]. Initially it was planned to additionally perform both types of compaction on the same asphalt mixtures, but due to work overload in both laboratories, we were not able to perform planned activities. For present study results of both past studies were compared [3, 4]. With impact compactor 4 different types of asphalt concrete mixtures were compacted (AC 8, AC 16, AC 16 and AC 32) [3]. With gyrator compactor 5 different types of asphalt mixtures were compacted (AC 8, AC 16, AC 32, SMA 8, SMA 1) [4]. With first study [3] it was proposed that ‘standardized model’ for impact compactor presented with eqn (1) should be replaced with ‘supplemented model’ presented with eqn (2).

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

$$\frac{1}{t(E)} = \frac{1}{t_\infty} - \left[\frac{1}{t_\infty} - \frac{1}{t_0}\right] * e^{\frac{-E}{T_1}} + F * e^{\frac{-E}{T_2}} \qquad (2)$$

With second study [4] it was proved that ‘standardized model 2’ for gyratory compactor presented with eqn (3) is less suitable for describing compaction process than ‘supplemented model’ for impact compaction presented with eqn (2).

$$\upsilon(ng) = \upsilon(1) - (K \cdot \ln ng) \qquad (3)$$

At first study [3] all samples were compacted with iron impact compactor according to EN 12697-31 in standard mould according to EN 12697-31 with diameters 101.6 mm and height between 61 mm and 66 mm. The compaction temperatures were for all samples set according to EN 12697-35. In Table 1 are presented compactabilities T_1 and T_2 calculated according to the ‘supplemented model’ for impact compactor (eqn 2).

Table 1. Average compactabilities T_1 and T_2 of asphalt mixtures compacted with impact compactor and calculated according to the supplemented model

	AC 8	AC 11	AC 16	AC 22
T_1	43.4	74.3	50.7	84.5
T_2	7.1	8.1	8.4	8.5
Coefficient of determination (r^2) between model and experimental data	0.997	0.998	0.998	0.999

At second study [4] 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. The compaction temperatures were for all samples set according to EN 12697-35. In Table 2 and 3 are presented compactabilities T_1 and T_2 calculated according to the supplemented model for impact compactor (eqn 2).

Table 2. Compactabilities T_1 of samples compacted with gyratory compactor and calculated according to the supplemented model

Dimension of specimen [mm]	AC 8 T_1	AC 16 T_1	AC 32 T_1	SMA 8 T_1	SMA 11 T_1
ø100, h=100	35.4	46.6	59.3	51.6	69.3
ø 150, h=100	32.9	53.3	59.0	53.5	50.0
ø 100, h=150	43.7	60.9	43.2	65.0	52.9
ø 150, h=150,	54.7	55.9	67.6	64.7	56.9
Average T_1 of asphalt mix	41.7	54.2	57.3	58.7	57.3
Average coefficient of determination (r^2) between model and experimental data	0.9999	0.9999	0.9999	0.9999	0.9999

Table 3. Compactabilities T_2 of samples compacted with gyratory compactor and calculated according to the supplemented model

Dimension of specimen [mm]	AC 8 T_2	AC 16 T_2	AC 32 T_2	SMA 8 T_2	SMA 11 T_2
ø 100, h=100	6.9	6.2	9.6	8.0	9.3
ø 150, h=100	5.4	8.4	9.0	8.6	7.9
ø 100, h=150	6.9	9.1	5.7	8.9	6.9
ø 150, h=150,	7.6	8.5	8.2	9.3	9.1
Average T_2 of asphalt mix	6.7	8.1	8.1	8.7	8.3

From the Tables 1 and 2 it can be seen that all compactabilities T_1 calculated according to the supplemented model for impact compactor have similar order of magnitude (from 32.9 to 69.3 for gyratory compactor and from 43.4 to 84.5 for impact compactor) . Similar orders of magnitude have also all compactabilities T_2 (Tables 1 and 3). From Tables 2 and 3 it can be seen that compactabilities T_1 and T_2 vary due to different dimension of specimens and different types of asphalt.
In Table 4 are presented compactabilities K calculated according to the standardised model from standard EN 12697-10 for gyratory compactor (eqn 3).

Table 4. Compactabilities K of samples compacted with gyratory compactor and calculated according to the 'standardised model 2' from standard EN 12697-10 for gyratory compactor

Dimension of specimen [mm]	AC 8 K	AC 16 K	AC 32 K	SMA 8 K	SMA 11 K
ø 100, h=100	4.02	4.22	4.25	4.35	4.14
ø 150, h=100	3.4	3.74	3.85	3.59	3.86
ø 100, h=150	3.73	3.12	3.22	3.83	4
ø 150, h=150,	3.82	3.19	3.32	3.58	3.66
Average K of asphalt mix	3.74	3.57	3.66	3.84	3.92
Average coefficient of determination (r^2) between model and experimental data	0.9969	0.9993	0.9993	0.9986	0.9981

From the Tables 2, 3 and 4 it can be seen that the values of compactabilities K calculated according to standard model and T_1, T_2 calculated according to the supplemented model for impact compactor have different order of magnitude. On average values of compactabilities K are almost ten times smaller than values of compactabilities T_1. From coefficient of determination in the Tables 2 and 4 it can be also seen that supplemented model for impact compaction better fits experimental data than standardised model for gyratory compactor. The other advantage of supplemented model is the fact that it contains t_∞ , that is the infinite thickness. So we can also calculate also bulk density and void content of asphalt specimen after infinite number of gyrations.

2.2. CEI and TDI calculated with supplemented model

The **Compaction Energy Index** (**CEI**), which is the value of the area under the densification curve from density of 8 gyrations to 92% of **maximal asphalt density** (**G_{mm}**), represents the work done during the construction period to achieve 8 % (V/V) air voids [5]. The **traffic densification index** (**TDI**), which is the value of the area under the densification curve from 92% density to 98% density, represents the work needed to resist traffic loading during pavement service life [5]. It is theorized that CEI represents the work applied by the roller to compact the mixture to the required density during construction [5]. Mixtures with lower values of CEI have better constructability and are desired; while too low a value of CEI could be an indication of a tender mixture and should be avoided [5].
The 98% of G_{mm} is considered the critical density, at which the mixture is approaching the plastic failure zone [5]. Mixtures with higher TDI values in this range are more desirable because they are expected to take more traffic loads during their life span [5].
From data for impact compactor we were not able to calculate CEI and TDI indexes due to the fact that we could not obtain values of maximal densities (G_{mm}), which are needed for such calculation.
In scope of this study we tried to calculate CEI and TDI indexes for samples compacted with gyratory compactor. In fact we calculate 20 CEI indexes (5 different asphalt mixtures with 4 different geometries of specimen) and 14 TDI indexes. The reason that we were not able to calculate 6 TDI indexes was, that at some geometries of specimen it was impossible to achieve 98% of G_{mm} or in other words it was impossible to produce asphalt specimen with 2% void content. In Figure 1 is graphically presented the compaction curve of sample, where both indexes could be calculated and in Figure 2 is the case, where it was not possible to calculate index TDI. The calculated void content at infinite number of gyrations for sample presented in Figure 2 was 2.55 % (V/V).

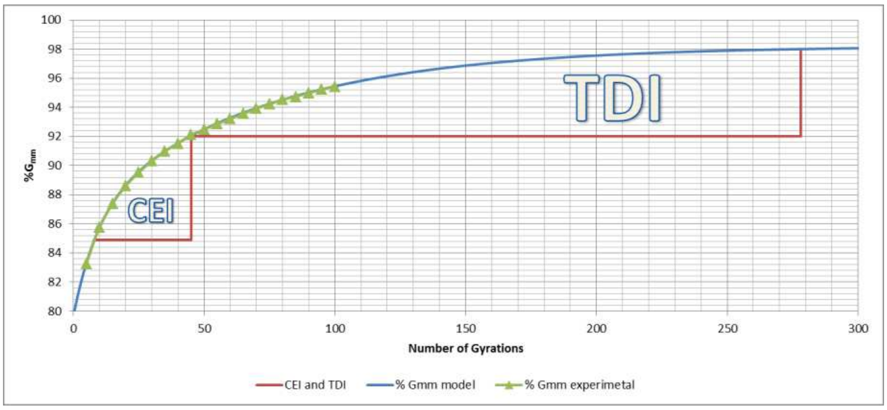

Figure 1: Compaction curve of SMA 11 (height 100 mm, diameter 100), where both indexes could be calculated

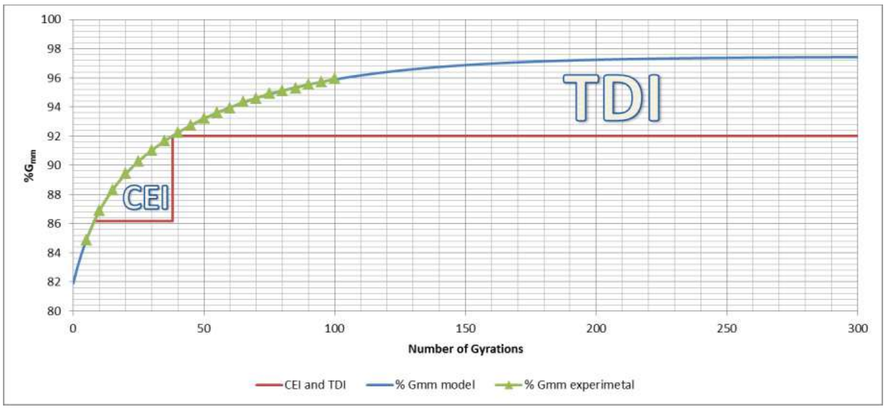

Figure 2: Compaction curve of SMA 11 (height 100 mm, diameter 150), where TDI index could not be calculated

From Figures 1 and 2 it can be seen that supplemented model fits experimental data. In Tables 5 and 6 are calculated values of indexes CEI and TDI. In Table 6 some values of TDI could not be calculated and they are marked with “infinite”, due to the fact that 2 % (V/V) of voids could not be achieved with compaction.

Table 5. Calculated index CEI of samples compacted with gyratory compactor

Dimension of specimen [mm]	AC 8 CEI	AC 16 CEI	AC 32 CEI	SMA 8 CEI	SMA 11 CEI
ø 100, h=100	15.1	33.1	77.8	79.9	171.4
ø 150, h=100	3.6	16.0	34.1	37.9	108.5
ø 100, h=150	61.0	80.5	141.5	105.2	86.8
ø 150, h=150,	110.0	18.7	64.1	53.9	94.9

Table 6. Calculated index TDI of samples compacted with gyratory compactor

Dimension of specimen [mm]	AC 8 TDI	AC 16 TDI	AC 32 TDI	SMA 8 TDI	SMA 11 TDI
ø 100, h=100	205.1	242.5	400.4	398.7	1041.0
ø 150, h=100	193.1	246.5	330.8	434.1	infinite
ø 100, h=150	infinite	infinite	infinite	791.1	631.1
ø 150, h=150,	infinite	350.5	940.5	494.9	infinite

We also assumed that compactabilities T_2 are correlated with CEI (Figure 3) and compactabilities T_1 are correlated with TDI (Figure 4). Correlations presented in Figures 3 and 4 were calculated only for one dimension of specimen (ø 100, h=100), due to the fact that for other dimensions some values of TDI are missing.

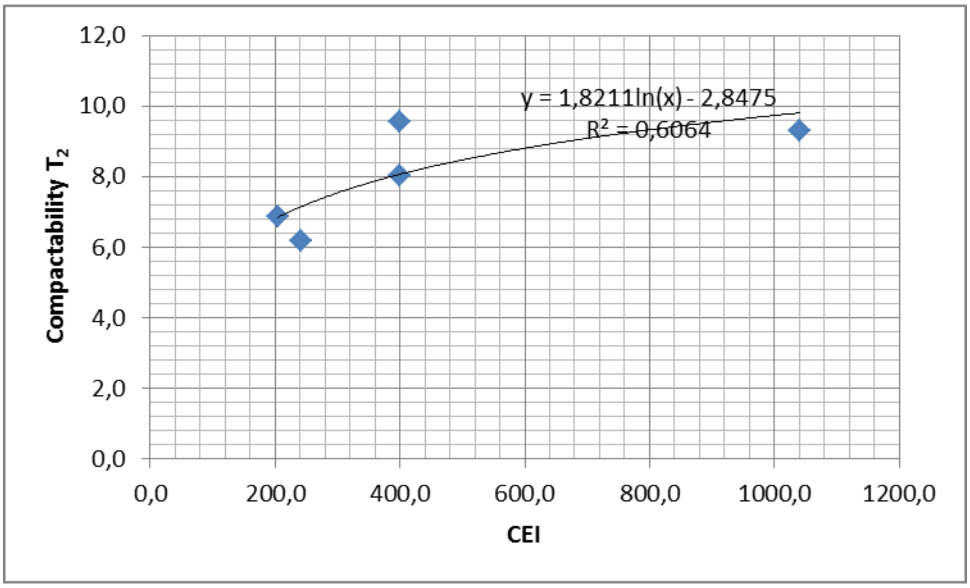

Figure 3: Dependence of compactability factor T2 on CEI

From Figure 3 it can be seen that there is relatively weak correlation between compactability factor T_2 and CEI. Correlation between compactability factor T_1 and TDI in Figure 4 is more promising.

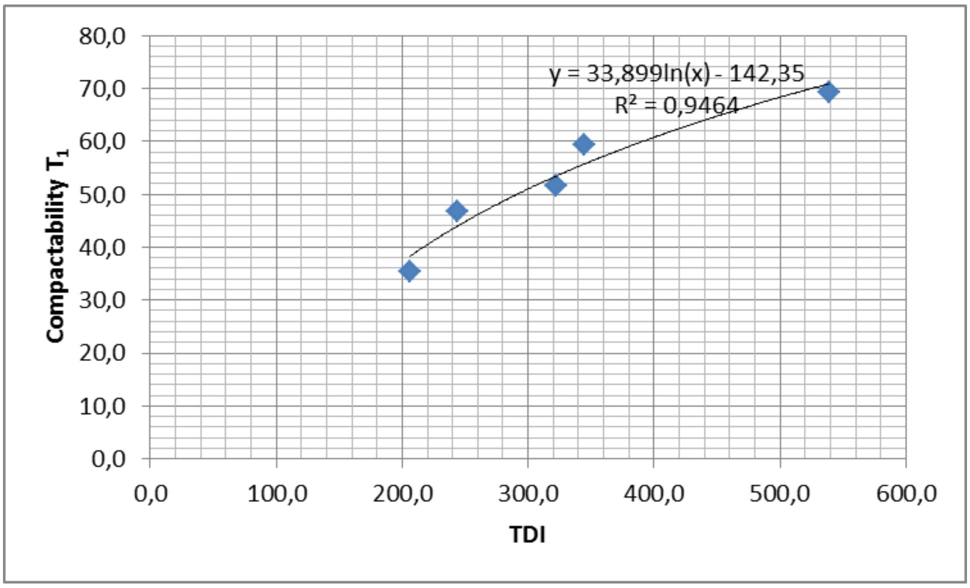

Figure 4: Dependence of compactability factor T_1 on TDI

3. CONCLUSION

With our studies we found out that "supplemented model" almost perfectly fits experimental compaction data for impact compactor and gyratory compactor. With supplemented model limiting height of compacted sample (t_∞) can be obtained. From limiting height user can calculate limiting density and limiting void content in the asphalt sample. Values of compactabilities T_1 and T_2 obtained with "supplemented model" have the same order of magnitude for both types of compaction. With this study we were not able to find simple correlation between compactabilities T_1 and T_2 obtained for impact compaction and gyratory compaction. Simple correlation was not found due the fact that principles of both types of compaction are different. We also tried to correlate compactability factor T_2 and construction densification index (CEI) where weak correlation was obtained. Correlation between compactability factor T_1 and traffic densification index (TDI) in was more promising, but it was not possible to calculate TDI for all dimensions of specimen. As final finding of this study we assume that compactability factor T_1 could be used as supplement or even replacement for TDI. Similarly compactability factor T_2 could be supplement for CEI.

In future studies we will perform gyratory and impact compaction on the same asphalt mixtures. We intend to include at least 4 different asphalt mixtures. With gyratory compactor at least 300 gyrations will be applied on each sample. With such study we will be able to better compare compactabilities T_1 and T_2 calculated with supplemental model for both types of compaction and evaluate possible correlations.

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