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COMPACTION DENSITY DETERMINATION OF THE ROAD ASPHALT LAYERS

This paper analyses the destructive and non-destructive methods for checking the degree of compaction of asphalt layers and their multi-criteria evaluation. The data obtained during laying of ACO 11+50 mm thickness was selected for the analysis. The bulk density was determined by using probes Troxler 3440, Troxler 2701 and from the drill cores in these given locations. According to the analysis accuracy, the probe Troxler 2701 used to determine the final degree of compaction of the construction asphalt layer and for the routine control of compaction is not suitable, even though when applying AHP (Analytic Hierarch Process) it was assessed as the second most suitable one.

Keywords: *asphalt mixture, compaction, quality control, destructive method, non-destructive method, nuclear density gauge, electrical density gauges, bulk density, drill core, multi-criteria evaluation*

1. Introduction

The asphalt is a significant building material used both in roads and for other building purposes. Up to 97 percent of the roads have a bituminous surfacing in the Czech Republic and 99 percent in Slovakia (situation to 1st July 2017). Road asphalt layers make the upper part of the flexible pavements, which is exposed to direct vertical and tangential wearing effects of the vehicles, which are then transmitted to further layers of the construction. The wearing course layer is immediately submitted to the effects of atmospheric and climatic influences.

Thus, the cover of the road should be water-resistant, flat, and should have proper anti-skid qualities, so that safe, fast and comfortable drive is ensured. To meet these requirements, it is necessary not only to ensure adequate building material [1], [2], [3] but also to keep the technology of the construction; otherwise there could be various defects such as permanent deformation [4] and adhesion failure between individual asphalt layers, [5], and when talking about wearing course layers one means inadequate surface properties. The extent of compaction influence all the above mentioned qualities and so its control plays a significant role in the process of building road communications.

2. Compaction quality control of asphalt mixtures

A proper compaction of the asphalt mixtures is crucial for reaching the required properties and ensuring the loading capacity, performance and length of life. By the compaction process, the permeability of the mixture decreases and by this the carrying capacity, weariness and rutting resistance increase. The extent of compaction depends to a certain level on the base, type of mixture, thickness of layers, used compaction technology and local conditions during laying. A well-designed and managed compaction process is crucial in order to reach good quality and long lifespan of the asphalt roads and vice versa; inadequate compaction leaves a high percentage of air pores in the road complex of layers, which becomes sensitive to moisture infiltration, oxidation and making of cracks [6]. On the other hand, over-compaction will result in very small amount of air pores in the construction layer, which could lead to asphalt bleeding on the surface of the road in the construction layer during the summer season, or it could result in a crushing of the aggregate, thus change of the mechanical qualities of the road, or rather the construction layer. It follows that when the road is inadequately compacted, one can see a non-standard degradation as a consequence of this and thus a decrease in its length of life.

The technology of compaction process is mainly determined empirically. However, there are studies that try to predict the performance of a mixture during a compaction process in the field conditions by various models, see [7]. Finding of the adequate model would enable designing the mixture so that after the compaction in the given local conditions, the mixture would have the required qualities.

The compaction control is carried out in two ways, the destructive method (drill core) and non-destructive methods NDG (Nuclear Density Gauge), or EDG method (Electrical Density Gauges). Globally, there is a rise in research, particularly in the area of non-destructive tests for determination of the compaction degree, e. g. by using sensors FBG (Fibre Bragg Grating) [8], or by Intelligent Asphalt Compaction Analyzer (IACA), which uses an artificial neuron net (ANN). By this ANN, the estimated value of the road bulk density under a roller during the compaction process is obtained [9]. Those two methods of finding the bulk density could be characterised as a continuous control of the compaction process; for now, they cannot be used as a tool for proving the concordance with the final layer, though, the advantages of the continuous method cannot be denied. The

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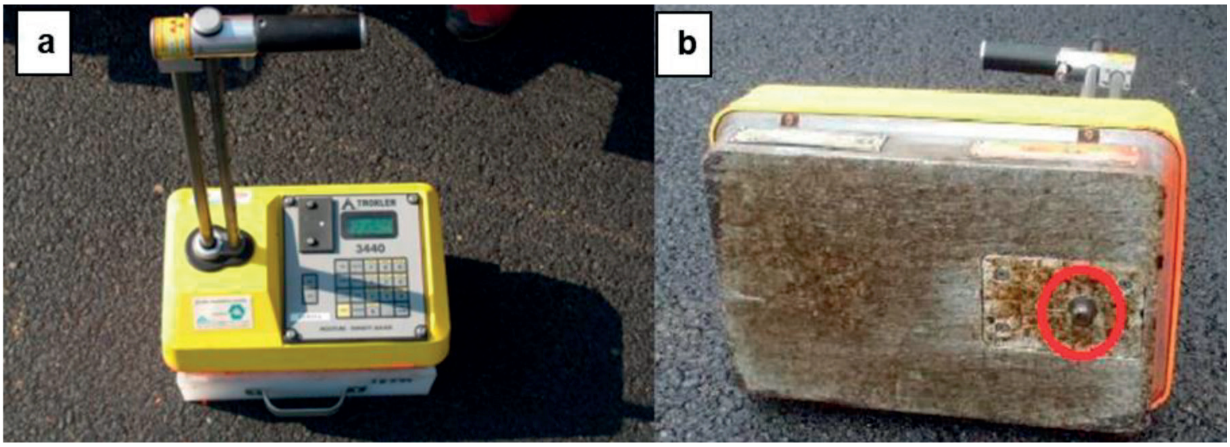

Figure 1 Troxler 3440, a - a view from the top; b - a view from the bottom [11]

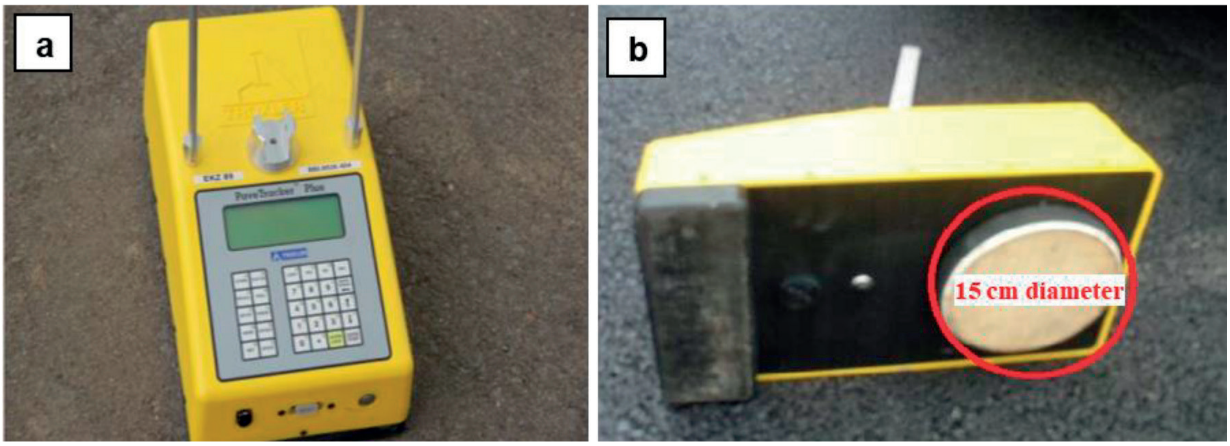

Figure 2 Troxler 2701-B, PaveTrackerTM, a - a view from the top; b - a view from the bottom [11]

study [10] focuses on examination of the achievable compaction quality in the whole length of the roadway. It was discovered that the bulk density of the layers of the asphalt road accidentally changes during the compaction process and that is caused by the re-orienting the aggregate to a random complex structures. Thus, there is 1.9 % possible difference in the density in the areas only 20 cm apart.

The control principle of the finished layers is described in the standard of Czech Republic *CSN 73 6121(Road building - Asphalt Pavement Courses - Construction and conformity assessment)*. The degree of the compaction (CD) is possible to control destructively on the drill cores, or after an agreement between the ordering party and the contractor also by the non-destructive method. Depending on the type of the asphalt mixture, the 96 or 98 % compaction degree is required. The asphalt mixtures marked S must reach 98 % of the compaction degree on the average and its compaction degree cannot decrease below 96 %. The compaction degree of the asphalt mixtures with the label + or "without any label" cannot decrease below 96 %.

3. Experiment

Individual methods for determination of the compacted bulk density of the asphalt differs from the point of view of time demands, technical equipment, calibration, principle of determination of the bulk density and its exactness. The aim of the experiment was to conduct a comparison of the methods: destructive method, NDG and EDG.

3.1 Destructive method

For obtaining core drill holes, the road core drilling equipment 60-0100 was used. Samples of the 100 mm diameter were acquired by using this equipment. After separating the layers, the bulk density was determined on the drill cores by using the procedure for a saturated dry surface.

3.2 Nuclear Density Gauge (NDG)

Measuring by this method was carried out by the radiometric set Troxler 3440, Figure 1. It is a transportable gauge for the fast determination of moisture, density and extent of compaction, especially soils, concrete and asphalt surfaces, without disturbing the construction of the measured material. The measuring probe contains shielded Cs 137 source of the 0.3 GBq activity and 241Am/Be of the 1.48 GBq activity. The weight of the NDG is 13 kilograms. Prior to each measurement, it is necessary to determine the daily calibration response, i.e. radiation intensity. Every 2 years the gauge needs to be inspected for the long-life stability in the certified laboratory; moreover, it is necessary to record once a month dose neutron equivalents of

***Table 1** Measured sections overview*

Section No.	Communication	Structural layer	Layer thickness	Asphalt mixture
1	III/4673 Stitina - Dehylov	wearing course	50 mm	ACO 11 +
2	II/467 Stitina - Kravare - Stepankovice	wearing course	50 mm	ACO 11 +
3	II/467 Stitina - Kravare I part	wearing course	50 mm	ACO 11 +
4	II/467 Kravare - Stepankovice II part	wearing course	50 mm	ACO 11 +
5	II/467 Stepankovice - Koberice III part	wearing course	50 mm	ACO 11 +

***Table 2** Statistical assessment of the bulk densities and compaction degree*

Section No.	No. of measurement		Bulk density in kg.m^{-3}			Compaction degree in %		
			Troxler 3440	Troxler 2701	Drill core	Troxler 3440	Troxler 2701	Drill core
1	8	min.	2 261	2 089	2 294	96.6	89.3	98.0
		mean	2 301	2 187	2 319	98.3	93.5	99.1
		max.	2 356	2 302	2 357	100.7	98.4	100.7
		min.-max.	95	213	63	4.1	9.1	2.7
2	7	min.	2 258	2 078	2 274	96.3	88.7	97.5
		mean	2 287	2 192	2 301	97.6	93.5	98.2
		max.	2 328	2 305	2 324	99.8	98.8	99.2
		min.-max.	70	227	50	3.5	10.1	1.8
3	10	min.	2 284	2 259	2 274	97.9	96.8	97.5
		mean	2 328	2 286	2 292	99.8	98.0	98.3
		max.	2 365	2 331	2 310	101.4	99.9	99.1
		min.-max.	81	72	36	3.5	3.1	1.6
4	14	min.	2 250	2 214	2 284	96.1	94.5	97.5
		mean	2 335	2 260	2 296	99.7	96.5	98.0
		max.	2 393	2 306	2 323	102.2	98.4	99.2
		min.-max.	143	92	39	6.1	3.9	1.7
5	16	min.	2 284	2 128	2 309	96.9	90.2	97.9
		mean	2 313	2 170	2 317	98.1	92.0	98.2
		max.	2 345	2 206	2 324	99.4	93.6	98.6
		min.-max.	61	78	15	2.5	3.4	1.7

the operators, which are continuously assessed in the national personal dosimetry service. The operators must be trained for work with a radioactive material.

3.3 Electrical Density Gauges (EDG)

The non-nuclear sensing device Troxler 2701-B, Pave Tracker TM, Figure 2, was used for the measurement. This device is using electromagnetic density indication. The PaveTracker Plus does not contain any radioactive material and so there is no need for any licence or any special training for operating this gauge. Its weight is approximately 6 kg. A regular calibration every 2 years must be executed in a certified laboratory, as well.

3.4 Course of experiment

The selection of the assessing parameters was chosen in order to make the mutual comparison of individual methods possible. Parameters (time for measurement preparation, time of measuring, bulk density assessment time and other costs) were found out when reconstructing roads in real traffic of the construction and from personal experience. For evaluation of the exactness, at one place the measuring NDG and EDG in both positions was carried out, and at the same place the drilling was executed. Data obtained by this measurement were subsequently divided into two evaluating files, which had the same input attributes of the constant thickness and composition of the laying mixture; the measured bulk density obtained from the drill was taken as a reference value.

3.5 Evaluation exactness

Measuring the level of compaction by all three methods was carried out on five individual sections on the wearing course layers, see Table 1. All measurements on five experimental sections were performed on one type of asphalt mix - ACO 11+ asphalt concrete with 50/70 paving grade. All the fractions, except aggregate filler, which were used for the production of bituminous mixture, were from Bucovice quarry. From a petrographic point of

Table 3 Compaction degree with the standard requirements and mutual comparison of them

Section No.	No. of measurement	No. of measurements with CD ≥ 96 %			CD Drill core > CD Troxler 3440	CD Drill core > CD Troxler 2701
		T 3440	T 2701	Drill core		
1	8	8	2	8	7	7
2	7	7	1	7	5	6
3	10	10	10	10	1	6
4	14	14	10	14	1	12
5	16	16	0	16	10	16

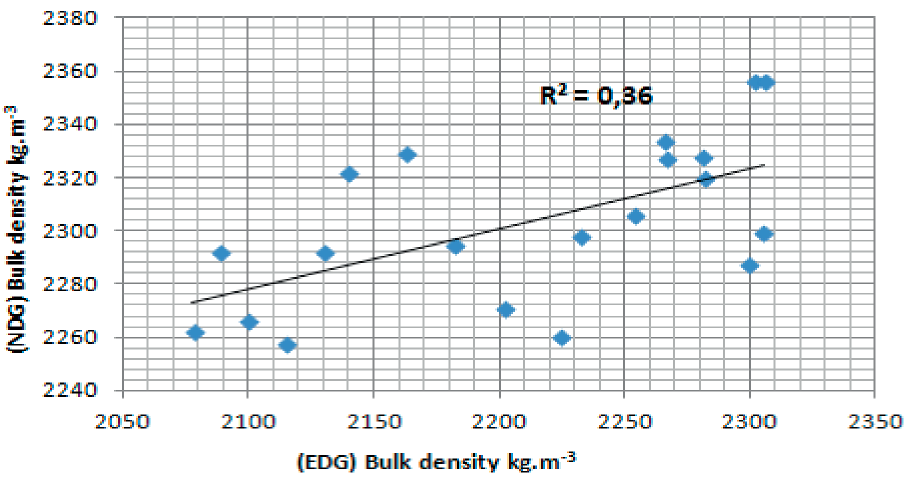

Figure 3 *The relationship between the method NDG and EDG*

view, it is a greywacke of gray to dark gray color with a brownish or greenish shade. The compaction degree is determined as a ratio of the compacted bulk density determined on the structural layer and reference bulk density determined on the Marshall Test specimen, i.e. cylinder test specimen. In the case of the destructive method, the bulk density of the drill core and Marshall specimen are determined by the same method, by using the hydrostatic scales, which means that this method can be considered to be a standard method that has the highest informative value. Both of the above described non-destructive methods were compared to the destructive method.

The basic statistical parameters of the compacted bulk density and the compaction degree of the compared sections are given in Table 2. One can conclude that the bulk density variance is the smallest in all the five assessed cases when determining the drill cores. The difference is by one third smaller when comparing to the non-destructive method by Troxler 3440. At the section number 5, the difference between maximal and minimal measured bulk density at the drill cores is four times smaller than by the Troxler 3440 measurement. The Troxler 2701 probe measurement displayed much worse results. The same results can be concluded when comparing compaction intensities determined by three methods. The difference between the compaction density determined on the drill cores and the Troxler 3440 probe is at individual sections equal to: No.1+0.8 %, No. 2 +0.6 %, No. 3 - 1.5%, No. 4 - 1.7%, No.5 - 0.8%. The difference between the compaction density determined on the drill cores and the Troxler 2701 probe is substantially higher, it reaches even cca. 6 %.

The bulk density assessment with the demand of the standard CSN 73 6121, which requires minimal compaction intensity of 96 % for the mixture ACO 11, is displayed in Table 3. During the checking tests carried out on the drill cores, it was possible to state that all five sections were compacted enough in their whole lengths. When evaluating the compaction density by the non-destructive probe Troxler 3440, exactly the same result can be concluded. When assessing the compaction density by the non-destructive probe T 2701, the number of satisfactory measurement was 23 out of 55.

Within finding out whether there is a certain dependency between the destructive method and both of the non-destructive methods, the conclusion is that none has been found. The coefficient of determination was near zero. When comparing both non-destructive methods, the coefficient of determination was between (0.3-0.4), Figure 3. However, even in this case it would be daring to claim that the dependency exists between these two methods.

3.6 Multi-criteria evaluation

In order to determine the relative weights, the quantitative method of pair comparison (the Saaty's method) was used. The essence is to construct a matrix expressing the relative values of a set of attributes. Five experts are asked to choose whether cost is very much more important, rather more important, as important, and so on down to very much less important, than operability. Each of these judgements is assigned a number on a scale. One common scale (adapted from Saaty), can be seen in Table 4.

A basic, but very reasonable, assumption is that if attribute A is absolutely more important than attribute B and is rated at 9, then B must be absolutely less important than A and is valued at 1/9. The degree of importance of individual criteria

***Table 4** The Saaty Rating Scale*

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

***Table 5** Pair preference of the criteria*

	Measurement accuracy	Price 1 measurement	Equipment price	Price adjustment	Time measurement	Time calibration	Activation time	Time finding density	Maintenance	Energy	Additional equipment	Weight
Measurement accuracy	1	9	9	9	9	9	9	9	9	9	9	9
Price 1 measurement	1/9	**1**	5	7	5	9	9	7	9	9	9	9
Equipment price	1/9	1/5	**1**	7	5	9	5	5	5	7	5	9
Price adjustment	1/9	1/7	1/7	**1**	1/3	5	1/3	1/5	1	1	1/5	1/5
Time measurement	1/9	1/5	1/5	3	**1**	9	7	5	5	7	5	9
Time calibration	1/9	1/9	1/9	1/5	1/9	**1**	1/7	1/9	1/7	1/5	1/7	1/9
Activation time	1/9	1/9	1/5	3	1/7	7	**1**	1/5	1/7	1/5	3	3
Time finding density	1/9	1/7	1/5	5	1/5	9	5	**1**	5	7	5	9
Mainentance	1/9	1/9	1/5	1	1/5	7	7	1/5	**1**	1	1/5	3
Energy	1/9	1/9	1/7	1	1/7	5	5	1/7	1	**1**	1/5	1
Additional equipment	1/9	1/9	1/5	5	1/5	7	1/3	1/5	5	5	**1**	5
Weight	1/9	1/9	1/9	5	1/9	9	1/3	1/9	1/3	1	1/5	**1**

***Table 6** Multi-criteria method evaluation of the bulk density determination on construction*

	Measurement accuracy	Price 1 measurement	Equipment price	Price adjustment	Time measurement	Time calibration	Activation time	Time finding bulk density	Mainentance	Energy	Additional equipment	Weight	*u* (Ai)	Range number
Troxler 3440	0.8	0.9	0.6	0	0.9	0	0.8	0.8	0.6	1	1	0.8	0.80	1
Troxler 2701	0	1	1	1	1	1	1	0.9	1	1	1	0.9	0.71	2
Drill Core	1	0	0.3	1	0	1	0.1	0.1	0.8	0.8	0.8	0	0.44	3
Scales	0.28	0.18	0.12	0.02	0.09	0.01	0.02	0.18	0.03	0.02	0.04	0.02		

was determined based on experience of the author, see Table 5. To determine the order of advantages of individual methods, from the point of view of the chosen criteria, the method of the Weighted sum product - WSA was used, see Table 6.

The order assessed by the WSA method is as follows that the most suitable method of the bulk density determination according to the chosen criteria was the Troxler 3440 equipment. Even though the exactness was unsatisfactory, The Troxler equipment 2701 is the second most suitable method. The third place is taken by the method of bulk density determination by using drill core. The exactness is the most important in this case. Despite using the AHP assessment, it is clear that destructive method is necessary especially when handing the construction for determination of the layer thickness and their connections. According to the standard, the drill cores are carried out every 1,500 m^2. It is without doubt that by this method one obtains the most reliable values of the bulk density; still this method is both equipment and time-demanding.

4. Conclusion

From the analysis of the measured results of the compacted bulk densities, or more precisely the compaction degree, it can be stated that the biggest informative value has the determination of the compaction intensity by the destructive method on the drill cores. In the case of resolving tests, it is possible to use only this method. The non-destructive method, when the compaction degree is determined by the Troxler 3440 equipment, is feasible in the process of compacting, and even when controlling the work performed. The results of the compaction intensity can differ from the real degree by cca 1 %. When measuring the degree of compaction by the radio-metric probe, it would be advisable that the obtained compaction degree was at the level of 99 %, or rather 97 % depending on the type of the asphalt mixture. From the presented results, it can be stated that the second equipment, i. e. Troxler 2701 probe, does not reach the sufficient exactness, not even the repeating measurement. It is neither possible to recommend it for the determination of the final compaction degree of the construction asphalt layer, nor for the continuous inspection of the compaction. Based on the obtained results it can be concluded that the AHP as a tool for the multi-criteria evaluation is not suitable for this particular case.

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