QUALITY ASSURANCE OF ASPHALT PAVEMENT

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Abstract

When laying asphalt layers, the compaction plays an important role. It also ensures the mutual arrangement of the various parts of the asphalt mixture so that the mixture reaches the optimal properties in terms of endurance, strength in terms of climatic conditions; thus guaranteed the desired lifetime period of the layer. The degree of compaction is characterized by the ratio of density found on the layer (destructive, non-destructive) and the reference volume density (Marshall body, control production test of the given section). The paper analyses the destructive and non-destructive methods for checking the degree of compaction of asphalt layers. The data obtained during laying ACO 11+ 50 mm thickness. The volume density was determined by using probes Troxler 3440, Troxler 2701 and from the boreholes 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.

Keywords: Asphalt mixture, compaction, quality control, destructive method, non-destructive method, Nuclear Density Gauge, Electrical Density Gauges

1 Introduction

The asphalt is a significant building material used both in road constructions and in other building purposes. The first references to using this building material go back to ancient times. The boom of the usage starts at the beginning of 20th century with the expansion of the petrochemical industry. Today, it is a widely used material and majority of road communications will not go without it. 97 percent of the road communications have an asphalt cover in the Czech Republic (situation to 1st July 2014). Road asphalt layers make the upper part of the non-solid road construction which is exposed to direct vertical and tangential wearing effects of the vehicles, which are then transmitted to further layers of the construction. The upper cover layer (abrasive) is immediately submitted to the effects of atmospheric and climatic influences. Thus, the cover of the road should be waterproof, 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, but also to keep the technology of the construction, otherwise there could be various defects such as adhesion failure among individual asphalt layers [4], and when talking about abrasive layers we mean inadequate surface properties.

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 increases. 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 [5, 11]. 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 a 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, we can see a non-standard degradation as a consequence of this, and so a decrease in its length of life. From the above mentioned it follows that the problem of a compaction quality control in the area of quality control or the field of quality assurance, is a highly important process. 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 field conditions by various models, see [6]. Finding of the adequate model would enable to design the mixture so that after compaction in the given local conditions, the mixture would have the required qualities. It is evident that the right design, choice of the aggregate and asphalt binders significantly influence the quality of the mixture. Nevertheless, the final quality of the finished road depends on the construction procedures and their control.The compaction control is carried out by two ways, the destructive method (core holes) 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 BraggGrating) [7] or by Intelligent Asphalt Compaction Analyzer (IACA) which uses an artificial neuron net (ANN). By this ANN, the estimated value of the road volume density under a roller during the compaction process is obtained [8]. These two methods of finding the volume 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 study focuses on the examination of the achievable compaction quality in the whole length of the roadway. It was discovered that the volume density of the layers of the asphalt road accidentally changes during the compaction process, and it 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 ČSN 73 612, in the Czech Republic. The degree of the compaction is possible to control destructively on the boreholes, 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 density in average, and its compaction density cannot decrease below 96 %. The compaction density of the asphalt mixtures with the label + or “without any label” cannot decrease below 96 %.

3 Experiment

Individual methods for determination of the compacted volume density of the asphalt layer differs from the point of view of time demands, technical equipment, calibration, principle of determination of the volume 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 machine 60-100 was used. Samples of the 100 mm diameter were acquired by using this machine. After separating the layers, the volume density was determined on the boreholes by using the procedure for a saturated dry surface.

3.2 Nuclear Density Gauge (NDG)

Figure 1 Troxler 3440 on the refference block [10]

Measuring by this method was carried out by radio-metric set Troxler 3440. It is a transportable gauge for a 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. Before every measurement, it is necessary to determine the daily calibration response, i.e. radiation intensity. Every 2 years the gauge needs to be inspected long-life stability in the certified laboratory; moreover it is necessary to record monthly dose neutron equivalents of the operators, which are continuously assessed in the national personal dosimetry service. The operators must be trained for work with a radioactive material Fig. 1.

3.3 Electrical Density Gauges (EDG)

The non-nuclear sensing device Troxler 2701-B, Pave Tracker TM 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 Fig. 2.

Figure 2 Troxler 2701-B, PaveTrackerTM [10]

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, volume 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 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 volume 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 abrasive layers, see Table 1. The compaction intensity is determined as a ratio of the compacted volume density determined on the construction layer and reference volume density determined on the Marshall test body, i.e. cylinder test body. In case of the destructive method, the volume density of the drill and Marshall body are determined by the same method, by using hydrostatic scales. Which means that this method can be considered to be a standard method that has the highest informative value. Both the above described non-destructive methods were compared with the destructive method.

Table 1 Measured sections overview

Section No.	Communication	Construction layer	Layer thickness [mm]	Asphalt mixture
1	III/4673 Štítina – Děhylov	abrasive	50	ACO 11 +
2	II/467 Štítina – Kravaře – Štepánkovice	abrasive	50	ACO 11 +
3	II/467 Štítina – Kravaře I part	abrasive	50	ACO 11 +
4	II/467 Kravaře – Štěpánkovice II part	abrasive	50	ACO 11 +
5	II/467 Štěpánkovice – Kobieřice III part	abrasive	50	ACO 11 +

The basic statistical parameters of the compacted volume density and the compaction intensity of the compared sections are given in the Table 2. We can conclude that the volume density variance is the smallest in all five assessed cases when determining the boreholes. The difference is by one third smaller when comparing with the non-destructive method by Troxler 3440. At the section number 5, the difference between maximal and minimal measured volume density at the boreholes 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 boreholes 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 compaction density determined on the boreholes and the Troxler 2701 probe is substantially higher, it reaches even ca. 6 %.
The compaction density assessment with the demand of the norm ČSN 73 6121, which requires minimal compaction intensity of 96 % for the mixture ACO 11 is displayed in the Table 3. During checking tests carried out on the holes, 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.

Table 2 Statistical assessment of the volume densities and compaction degree

Section No.	No. of measure-ment		Volume density in [kg/m³]			Compaction intensity [%]		
			Troxler 3440	Troxler 2701	Bore hole	Troxler 3440	Troxler 2701	Bore hole
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

Table 3 Compaction density comparison with the standard requirements and mutual comparison of CD

Section No.	No. of Measurement	No. of measurements with CD ≥ 96 %			CD borehole › CD Troxler 3440	CD borehole › CD Troxler 2701
		T 3440	T 2701	Borehole		
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

3.6 Multi-criteria evaluation

In order to determine the density, the quantitative method of pair comparison (the Saaty's method) was used. The degree of importance of individual criteria was determined on the basis of empiric experience of the authors, see Table 4. To determine the order of advantages of individual methods from the point of view of the chosen criteria, the method of the Weight sum product – WSA was used, see Table 5.

Table 4 Pair preference of the criteria

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

Table 5 Multi-criteria method evaluation of the volume density determination on construction

	Measurement accuracy	Price 1 measurement	Equipment price	Price adjustment	Time measurement	Time calibration	Activation time	Time finding vol. weight	Mainentance	Energy	Additional equipment	Weight	Other	u (Ai)	Place
Troxler 3440	0,8	0,9	0,9	0	0,9	0	0,8	0,8	0,6	1	1	0,8	0,8	0,83	1
Troxler 2701	0	1	1	1	1	1	1	0,9	1	1	1	0,9	0,8	0,72	2
Drill Core	1	0	0,3	1	0	1	0,1	0,1	0,8	0,8	0,8	0	0,5	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	0,01		

The order assessed by the WSA method is as follows, the most suitable method of the volume density determination according to the chosen criteria was the Troxler 3440 machine. Even though the exactness was unsatisfactory, The Troxler machine 2701 is the second most suitable method. The third place is taken by the method of volume density determination by using core holes. This destructive method is necessary especially when handing the construction for determination of the layer thickness and their connections. According to the standard, the core holes are carried out every 1,500 m^2. It is without doubt that by this method we obtain the most reliable values of the volume density; still this method is both equipment and time-demanding.

4 Conclusion

From the analysis of the measured results of the compacted volume densities, or more precisely the compaction degree, we can state that the biggest informative value has the determination of the compaction intensity by the destructive method on the boreholes. In 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 machine, 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 ca 1 %. When measuring the degree of compaction by radio-metric probe, it would be advisable that the obtained compaction degree was on the level of 99 %, or rather 97 % depending on the type of the asphalt mixture. From the presented results, we can state that the second machine, i. e. Troxler 2701 probe does not reach 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.

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