The object of this study is the compaction methods of asphalt mixtures under laboratory conditions.

The experience of determining the physical properties of coarse-grained asphalt concretes taken from the layers of the road pavement structure shows that their values do not correspond to those of the samples obtained by laboratory compaction using the pressing method. In 90 % of cases, the density of cores exceeds the density of laboratory samples while the indicators of void content and water saturation are significantly lower than for laboratory samples. The compressive strength indicators of asphalt concrete are almost independent of compaction methods and are not very informative. All of the above leads to the conclusion that the methods of laboratory compaction by pressing do not meet modern requirements.

Low values of water saturation and void content of cores and laboratory samples compacted with a gyrator allow us to argue about outdated approaches to the design of grain compositions of asphalt concrete. Low-informative indicators of compressive strength indicate the need to use other mechanical characteristics that will make it possible to predict the properties of asphalt concrete in the pavement, for example, rutting resistance. As a summary, template solutions in the design of asphalt concrete warehouses and physical and mechanical characteristics are necessary only to establish compliance with the requirements of regulatory documents.

The current work shows that it is almost impossible to predict the properties of asphalt concrete based on laboratory samples obtained by pressing.

All this leads to the need to change the regulatory framework, which is possible by using regulatory documents of the countries in the European Union and the United States of America

Keywords: compaction method, rutting resistance, compressive strength, void content, water saturation of asphalt concrete

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DETERMINING THE INFLUENCE OF COMPACTION METHODS ON THE PHYSICAL-MECHANICAL PROPERTIES OF ASPHALT CONCRETE SAMPLES

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1. Introduction

Asphalt concrete is one of the most common road pavement materials. Correct prediction of the properties of this material is a guarantee of reliable operation during the planned service life. Prediction of the properties of asphalt concrete in road pavements is carried out at the stage of composition selection under laboratory conditions. To this end, it is necessary to use samples made in a way that makes it possible to get a material that is as close as possible to the production compaction in the road pavement in terms of its properties.

There is a common problem of inconsistency of the properties of asphalt concrete samples made under laboratory conditions by the method of pressing with the properties of samples taken from asphalt concrete layers from the road.

The solution to this problem is relevant and possible through analysis of the results from determining the properties of asphalt concrete produced under laboratory conditions by the method of pressing and gyratory compaction and under production conditions by rolling.

2. Literature review and problem statement

With the beginning of the use of asphalt concrete as a pavement layer, the issue of making samples for researching its physical and mechanical properties under laboratory conditions and quality assessment arose. The main purpose of laboratory research is to predict the technological, physical-mechanical, operational characteristics, and durability of asphalt concrete. At the same time, it is important that the samples produced in the laboratory are representative and correspond as much as possible to the properties of the material obtained under the conditions of industrial compaction [1, 2]. Various methods of laboratory compaction of samples emerged during various stages of the evolution of asphalt concrete research. Among them are impact tamping, static pressure, vibration, vibration together with pressing, rotational compaction, rolling with a rigid sector or a pneumatic wheel. The developers believed that those methods correspond to a certain extent to the conditions of compaction of asphalt mixtures under production conditions, which, in turn, allows predicting the operational characteristics of asphalt concrete in the pavement [3].

One of the first compaction methods of asphalt mixtures was the method by Hubbard and Field [3]. The method is based on two-stage compaction, first by impact, and at the second stage by static loading on a hydraulic press for a given time. The use of this method is intended for the production of sand mixtures that are not common in road constructions. The compaction process is quite complex and takes a lot of time.

One of the most common methods of compacting asphalt mixtures is the Marshall impact compaction method [3]. According to this method, asphalt concrete samples are compacted using an impact load, which is applied from two sides of the mold alternately. The use of the Marshall method is implied by modern regulatory documents in the countries of the European Union [4] and the United States of America [5]. The Marshall method of compaction from one dock has become widespread and is used to this day, but it has a number of disadvantages, including the possibility of crushing crushed stone grains during the impact of the load.

In France, in the central laboratory of roads and bridges, asphalt concrete samples were manufactured using the Duriez method [6]. The essence of the compaction method was to apply static pressure to cylindrical forms with an asphalt mixture. Duriez's principle is used as the main method of compaction in the regulatory documents of some countries (DSTU B B.2.7–319 Asphalt-concrete mixtures and road and airfield asphalt concrete. Test methods) and by modern researchers [7, 8].

The compaction methods listed above have one common drawback – the lack of movement of mineral grains during compaction, which leads to poor packing of mineral material grains and their crushing in a much larger volume than during production compaction.

«Kneading Compactor» was designed to obtain samples that are as close as possible in properties to asphalt concrete compacted in pavement. In contrast to the compaction methods discussed above, during compaction by this method, the load is applied for a short time to a sector of a cylindrical shape, which is 1/6 of the surface area of the sample. The pressure applied at a frequency of 0.4 seconds is 3.45 MPa. After loading, the form turns 60 degrees. Compaction continues for 150 load cycles [9, 10]. The disadvantage of this compaction method is the open upper part of the mold and the hardening of the mixture during the compaction process. This can lead to uneven density distribution.

Achieving the required density of asphalt concrete is possible by applying much lower pressure while ensuring the rotation of a cylindrical shape with an asphalt mixture. This method of compaction is called gyratory [11, 12]. After a large number of tests under the SHRP SuperPave (Strategic Highway Research Program) program, a press design with an inclination angle of 1.16°, a load of 600 kPa, and a mold rotation speed of 30 revolutions per minute was adopted [13]. Subsequently, this compaction method became the most widespread in the USA, and its use in the countries of the European Union is also accepted [14].

Some researchers proposed to use various methods simulating compaction with rollers to compact asphalt concrete samples in the form of slabs. Among them is compaction using a pneumatic wheel [15], but such a device has a rather complex design for moving the wheel during compaction. Linear compactor is described in [16], in which compaction occurs with the help of a metal wheel that transfers the load to the mixture through a number of metal plates vertically installed in the form. A roller [17], in which compaction occurs by transmitting pressure through a metal cylinder rolling on the plate surface. And sector presses [18, 19] are standardized in [20]. Sectoral presses simulate the impact of a smooth roller on a specimen. Ukrainian scientists dealt with the issue of asphalt concrete compaction using a sector press [21, 22]. The main disadvantages of slab formation are the spread of asphalt concrete property values by area and thickness, as well as the need to select compaction modes depending on the type and type of asphalt concrete. The production of plate samples has become widespread for the subsequent cutting of cylinder or parallelepiped samples from them.

The authors of [1] showed the influence of different methods of compaction on the physical and mechanical properties of asphalt concrete samples, from which it was concluded that the gyrator compaction method gives the best results in terms of indicators of physical and mechanical properties. But the questions related to the comparison of the results of gyrator compaction and industrial compaction remained unaddressed.

In [2], a comparison of the physical and mechanical properties of asphalt concrete made under laboratory conditions with samples obtained as a result of industrial compaction was performed. It is shown that the quality of compaction of laboratory samples significantly affects the results of determination of mechanical characteristics than for production compaction samples. However, the obtained data must be verified using coarse-grained dense asphalt concrete.

Researchers in [7, 8] use the method of compaction by pressing for the production of asphalt concrete samples and subsequently determine the physical and mechanical properties without evaluating the properties of asphalt concrete in road wear layers, that is, after production compaction.

In [15], the effect of different types of granulometry on the compactability of asphalt concrete samples is shown, from which it follows that the same method of compaction for continuous mixtures can give a satisfactory result, and when using discontinuous mixtures, it is unsatisfactory. That is, based on the results of the study of one composition of asphalt concrete, it is impossible to unequivocally state that this result will be confirmed for all other compositions. This leads to the need to investigate different compositions of mixtures within the same type for compaction by different methods.

Gyratory compaction is one of the most common methods of asphalt concrete compaction used in Europe and the United States of America. This compaction technique makes it possible to obtain cylindrical samples of asphalt concrete that do not require further preparation. In this regard, it is relevant to compare the results of laboratory samples produced by pressing and gyratory compactor with core samples taken at the place of installation of the asphalt concrete layer. In the literature, there are almost no results of studying the properties of coarse-grained dense asphalt concrete on samples made using a gyratory compactor.

In the reviewed literature, there are no large-scale studies on the influence of laboratory sample compaction methods on the physical and mechanical properties of asphalt concrete samples from coarse-grained dense asphalt mixtures.

Thus, there is a need to investigate the influence of the most common compaction methods in the world and Ukraine on the physical and mechanical properties of dense asphalt concrete.

3. The aim and objectives of the study

The purpose of our work is to determine the influence of compaction methods of asphalt concrete samples in the laboratory on their physical and mechanical properties, and to compare them with the results of production compaction.

To achieve the goal, the following tasks were set:

– to analyze the physical properties of asphalt concrete (water saturation and void content) produced using different compaction methods, taking into account current national regulatory documents (compaction by pressing) and modern methods of compaction (gyrational compaction);

– to evaluate the compressive strength of asphalt concrete samples at temperatures of 20 and 50 °C and rutting resistance when using different compaction methods.

4. The study materials and methods

The object of our study is asphalt concrete compaction methods and the physical-mechanical properties of asphalt concrete samples.

The main hypothesis of the study assumes that as a result of the compaction of asphalt mixtures under laboratory conditions, the properties of asphalt concrete should be as close as possible to field compaction.

The range of asphalt mixtures in the world is quite wide; for the study, based on experience, coarse-grained asphalt concretes of type A1 were chosen. All mixtures were selected in 2020 at the production sites, and in 2021 at the sites of a arrangement of asphalt concrete layers on roads of state importance throughout the territory of Ukraine, with subsequent selection of cores. All asphalt mixtures had a different grain composition within the normalized limits.

As methods of asphalt concrete compaction, the method of pressing for 3 minutes at a load of 30 MPa and the method of gyratory compaction according to [14] will be used.

For the gyratory compactor, there are several parameters set during compaction:

– angle of inclination of the axis of the sample;
– load on the sample;
– the number of revolutions.

These parameters for the purposes of the study were set according to the SHRP SuperPave system:

– the angle of inclination of the axis of the sample is 1.16°;
– sample load of 600 kPa;
– the number of revolutions is 100.

The number of revolutions is set to 100, which according to SHRP SuperPave corresponds to roads with a significant load. This is due to the fact that most of the roads that were to be built, repaired, or reconstructed belonged to the I and II technical categories.

The study of physical and mechanical properties of asphalt concrete samples was carried out in accordance with national technical conditions according to the methods outlined in DSTU B B.2.7–319. Among the indicators not standardized by the current normative documents, the rut depth was determined according to [23].

5. Results of investigating the physical and mechanical properties of asphalt concrete compacted in different ways

5. 1. Results of determining the physical characteristics of asphalt concrete

One of the most important indicators of the physical properties of asphalt concrete is the void content, but in some regulatory documents preference is given to the indicator of water saturation. According to DSTU B B.2.7–119, the indicator of void content is determined only during the selection of the composition of asphalt concrete and during periodic quality control of asphalt mixtures, and the indicator of water saturation during the selection, acceptance, and acceptance control, and quality control of the arrangement of the asphalt concrete layer. The preference for water saturation is probably due to the simpler method of determination.

The water saturation indicator, unlike the void content indicator, takes into account only the open pores of asphalt concrete into which water can enter during its determination. But one of the main functions of the pores in asphalt concrete is to compensate for the change in volume during thermal expansion of the binder. Thus, the distribution of closed and open pores is not always the same and may change even within the asphalt mixtures of the same type. In the course of the monitoring, it was established that the number of closed pores ranged from 10 to 90 % in relation to the indicator of void content for coarse-grained dense asphalt concrete type A1. In this regard, the dependence of the void content indicator on the compaction method of asphalt concrete samples in the laboratory was considered (Table 1).

One of the conditions for selecting the composition according to DSTU B B.2.7–119 is the value of the void content indicator in the range from 2 to 5 % for most climatic zones. This is different from the requirements of the SHRP SuperPave program, in which according to the results of the selection in the laboratory, it is necessary to obtain an indicator of void content equal to 4 % (which, by the way, meets domestic requirements). Subsequently, this indicator is monitored abroad with cores and its value should not exceed 7 %.

Our results show that the value of the void content, determined during compaction by pressing and compaction by a gyrator, is significantly different. In the case of using a gyrator, the void content is significantly less and, in most cases, does not meet the requirements of regulatory documents for its value, i.e., below 2 %. At the same time, for standard compaction, this indicator meets the requirements in all but one case, which allows us to assume the correct selection of asphalt concrete composition according to national requirements.

Worth noting are the resulting values of compaction coefficients shown in Fig. 1, 2, calculated for two methods of laboratory compaction. When compacted by pressing, its value in most cases exceeds one, and only in three cases it is less than one.

When compacting samples with a gyrator, the values of the compaction coefficient almost never exceed 1.00, which indicates greater reliability of the results of the physical and mechanical properties of asphalt concrete samples obtained by compacting with a gyrator.

Table 1

Value of void content and compaction coefficient from the compaction method for asphalt concretes of type A1

Sample No.	Void content, %					Compaction coefficient	
	Regulatory requirements		Compaction method			Compaction method	
	min	max	Press	Gyrator	Industrial	Press	Gyrator
1724/21	2	5	3.3	0.5	2.9	1.00	0.98
1801/21	2	5	4.0	0.8	1.6	1.03	0.99
1802/21	2	5	2.2	0.2	0.9	1.01	0.99
1984/21	2	5	3.9	1.5	2.3	1.02	0.99
2000/21	2	5	2.4	0.0	1.2	1.01	0.99
2018/21	2	5	3.3	0.9	1.3	1.02	1.00
2057/21	2	5	3.7	1.0	3.7	1.00	0.97
2094/21	2	4	4.1	1.0	3.4	1.01	0.98
2136/21	2	5	4.2	1.8	6.9	0.97	0.95
2235/21	2	5	3.1	0.3	0.7	1.02	1.00
2243/21	2	5	2.8	0.1	3.2	1.00	0.97
2273/21	2	5	4.7	1.6	5.8	0.99	0.96
2282/21	2	5	4.3	1.9	3.5	1.01	0.98
2313/21	2	5	4.8	2.0	2.0	1.03	1.00
2316/21	2	5	2.7	0.3	1.5	1.01	0.99
2364/21	2	5	2.3	0.1	1.6	1.01	0.98
2402/21	2	5	3.4	1.0	2.6	1.01	0.98
2514/21	2	5	4.0	1.2	3.2	1.01	0.98
1202/20	2	5	3.2	2.0	0.6	1.03	1.01
1218/20	2	5	3.9	2.3	1.1	1.03	1.01
1235/20	2	5	4.8	2.5	1.5	1.03	1.01
1242/20	2	5	6.3	3.9	8.1	0.98	0.95
1257/20	2	5	4.5	1.7	1.7	1.02	1.01
1508/20	2	5	5.0	3.0	2.1	1.03	1.01
1512/20	2	5	3.2	1.6	2.0	1.01	1.00
1563/20	2	5	3.7	2.1	0.5	1.03	1.02
1703/20	2	5	3.3	0.9	0.7	1.03	1.00
1784/20	2	5	2.9	0.6	0.3	1.03	1.00
1938/20	2	5	5.5	3.9	4.9	1.01	0.99
2052/20	2	5	2.8	0.4	1.8	1.01	0.98
2068/20	2	5	4.1	1.7	2.5	1.01	1.00
2190/20	2	5	4.0	2.4	3.2	1.01	0.99
2282/20	2	5	3.0	1.4	2.4	1.01	0.99
2355/20	2	5	3.7	0.9	1.9	1.02	0.99
2406/20	2	5	3.6	1.7	1.4	1.02	1.00
2617/20	2	5	4.4	2.0	1.2	1.03	1.01

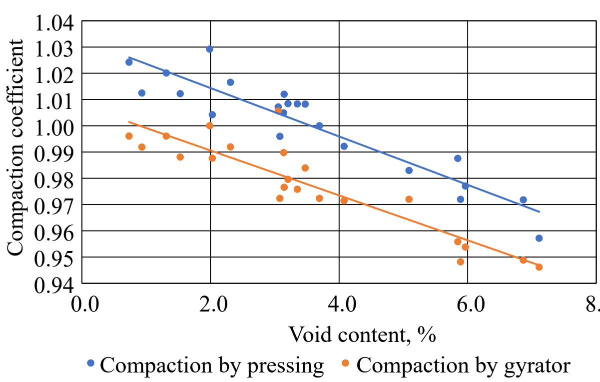

Fig. 1. Dependence of compaction coefficient on void content and compaction method when performing monitoring in 2021

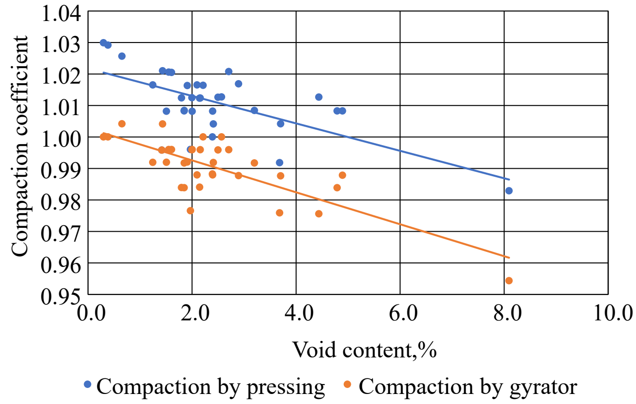

Fig. 2. Dependence of compaction coefficient on void content and compaction method when performing monitoring in 2020

In addition, plots in Fig. 1, 2 prove the possibility of evaluating the quality of compaction by the indicator of void content, as provided for in the SHRP SuperPave program, but the condition for compliance with such an evaluation method is the compliance of the asphalt concrete composition of its selection.

The indicators of water saturation and void content for coarse-grained asphalt concretes of type A1 compacted by various techniques were considered (Table 2).

The water saturation of the considered asphalt concretes in the case of compaction in the pavement and gyratory compactor in all cases meets the requirements of regulatory documents (but modern national regulatory documents do not regulate the minimum values of the water saturation index). According to the SHRP SuperPave program, the value of this indicator is not regulated. When compacted by pressing, the value of water saturation for the two asphalt concretes given in the table does not meet the requirements of regulatory documents, which indicates the non-compliance of the compaction method.

The values of the void content index of the same asphalt concrete are somewhat different from the requirements of regulatory documents.

In three cases, it does not meet the requirements of Ukrainian standards for this indicator with standard compaction by pressing but meets them when using a gyratory compactor.

When using a gyratory compactor, values lower than 2 % were obtained for part of the asphalt concrete, and this indicates the non-compliance of this indicator with the requirements of national regulatory documents (from 2–5 %). If we compare these values with the requirements of the SHRP SuperPave program, only two asphalt concretes come close to them (3.9 % against the requirements of 4.0 %).

For the samples taken from the pavement layers, the value of the void content indicator is not regulated by national regulatory documents, but in some cases, it was less than 2 %, which does not meet the requirements for laboratory samples.

According to the SHRP SuperPave program, the value of the void content indicator for samples taken from the installed pavement should be from 4 to 7 %. Only three asphalt concretes meet this condition, only one asphalt concrete meets both conditions for laboratory samples and pavement cores.

Table 2

Comparison of water saturation and void content and their compliance with regulatory documents

Binder content, %	Void content, %				Water saturation, %			
	Compaction method			Requirements of regulatory documents of Ukraine*/USA**	Compaction method			Requirements of regulatory documents of Ukraine
	Press	Gyrator	Industrial		Press	Gyrator	Industrial	
4.4	3.3	0.5	2.9	2–5/4 – laboratory specimens; –/4–7 – cores	2.5	0.39	2.3/1.0	Not more than 3.5 (4.0) for samples with a pavement of +1.5 %
4.5	3.3	0.9	1.3		2.6	0.42	0.6/1.02	
4.5	3.7	1	3.7		2.6	0.46	2.6/1.00	
4.4	4.7	1.58	5.8		2.2	0.89	3.8/0.99	
4.4	4.8	2	2.0		3.9	1.18	0.8/1.03	
4.3	3.8	1.5	4.6		2.7	0.68	3.0/0.99	
4.5	3.2	2	0.6		2.8	1.37	0.9/1.03	
4.5	4.8	2.5	1.5		4.5	2.10	1.1/1.03	
4.5	6.3	3.9	8.1		3.2	0.67	4.2/0.98	
4.5	5	3	2.1		3.2	1.57	1.3/1.03	
4.2	5.5	3.9	4.9		2.6	0.33	0.6/1.01	
4.5	4.5	2.1	–		3.8	1.65	–	
4.5	4.2	1.8	–		3.2	1.33	–	
4.5	4	2.4	3.2		2.3	0.47	1.2/1.01	
3.9	6	4.6	–		5.1	2.86	–	
4.5	4.5	1.4	–		3.5	1.15	–	

*Note: non-compliance with regulatory documents is marked in red, compliance with regulatory documents is marked in green; * – DSTU B V.2.7-119; ** – SHRP SuperPave*

5. 2. Results of determining the mechanical characteristics of asphalt concrete

To assess the impact of compaction methods on the mechanical properties of asphalt concrete samples, compressive strength at temperatures of 20 and 50 °C was determined. Comparison of strength values for different compaction methods is represented graphically (Fig. 3). The given result shows that the compaction method has almost no effect on the value of the compressive strength of asphalt concrete samples made in the laboratory.

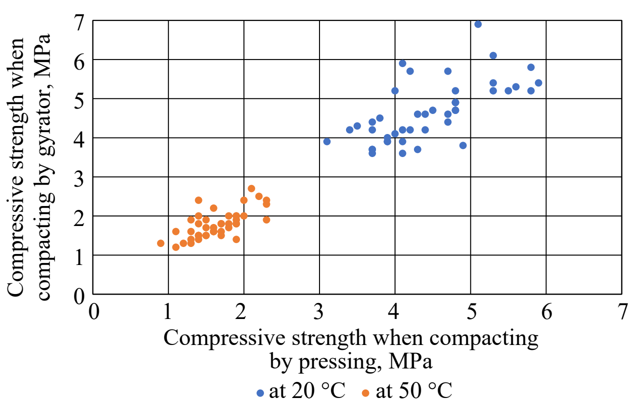

Fig. 3. Dependence of the compressive strength of asphalt concrete on the method of laboratory compaction

To the greatest extent, the complex stress-deformed state of asphalt concrete corresponds to the method of determining the depth of the rut [23] with the given values of the number of wheel passes along the track and temperature. The ability to use the compressive strength at 50 °C to predict the path resistance index can confirm the relationship between them (Fig. 4).

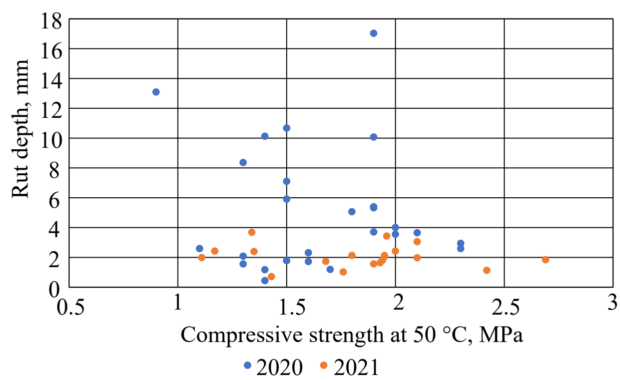

Fig. 4. Dependence of the rut depth on the compressive strength index at a temperature of 50 °C for coarse-grained asphalt concretes of type A1

One can see the absence of any dependence between these indicators. This makes it possible to assert the need to assess the mechanical properties of asphalt concrete based on the rutting resistance and other indicators that fully reveal the resistance of asphalt concrete to mechanical impact in the road pavement.

6. Discussion of results of investigating the physical and mechanical properties of asphalt concrete

In most cases, the void content of the cores is much closer in value to the void content of laboratory samples compacted with a gyrator (Table 1), which indicates that the compaction of laboratory samples in accordance with the regulatory documents of Ukraine does not correspond to production compaction. In contrast to [1], in which it is shown that gyrator compaction gives the best results in terms of physical and mechanical properties, our work compares the results with production compaction This makes it possible to say that the results of gyrator compaction are close to the results of compaction under production conditions.

In the case of calculating the compaction coefficient for gyratory samples (Table 1), its value does not exceed 1.01, and for some samples it was 0.95. The low value of the compaction coefficient in this case confirms the assumption of insufficient compaction of the asphalt concrete (on the object of the road pavement installation), caused by the comparison with the results of standard compaction by pressing.

Asphalt concrete under the code 1938/20, for which the value of void content under standard compaction was 5.5 % (does not meet the requirements of regulatory documents), is particularly noteworthy. When it was compacted with a gyrator, it was about 4 %, and for the cores it was 4.9 %, which fully meets the requirements of the SHRP SuperPave program.

Analysis of the results regarding void content and the compaction coefficient obtained for asphalt concrete during monitoring tests in 2020 (Fig. 1) and 2021 (Fig. 2) reveals a linear relationship between these indicators. When compacting laboratory samples by pressing, the compaction factor exceeds 1.00 in almost 50 % of cases. Such values indicate insufficient compaction of laboratory samples and, in turn, false assessment of the properties of asphalt concrete based on these samples.

The value of compaction coefficients greater than 1.00 (Fig. 1, 2) when using the method of compacting asphalt concrete by pressing introduced such a concept as «overcompaction» into the lexicon of road workers. «Over-compaction» means that the production capabilities have increased, and the adopted design system does not answer the question of whether it is permissible, and everything that is not prohibited is allowed.

The reasons for the low values of the void content index for cores and laboratory samples compacted with a gyrator lie in the content of the binder and the requirements for the grain composition of asphalt concretes, which are set out in regulatory documents. It is possible to increase the value of the void content index by reducing the amount of binder, but most manufacturers pay attention to the reference values of the binder content set out in regulatory documents. They indicate the values of the approximate content of bitumen in asphalt mixtures, which for a coarse-grained asphalt mixture of type A1 is from 4.5 to 6.0 %. Considering this, most contractors prescribe a binder content of at least 4.5 %, while the optimal binder content for coarse-grained asphalt concrete mixes of type A1 is from 3.5 to 4 %.

Low values of void content of asphalt concrete lead to increased rutting in asphalt concrete layers. National regulatory documents provide for only one standardized strength indicator at a temperature of 50 °C – compressive strength.

Compressive strength indicators do not depend on the method of compaction (Fig. 3). The reason for this is known – it is the inconsistency of the load scheme on the asphalt concrete sample during the test to the operating conditions of asphalt concrete in the road pavement. When determining the strength, the asphalt concrete sample is subjected to compression without lateral pressure, that is, the mineral parts of the asphalt concrete have the ability to move almost freely during compression. But even with a static load in the road pavement, the layer of asphalt concrete is in a complex stress state, in which there are several types of deformation. That is, to assess the mechanical properties of asphalt concrete, it is necessary to use methods that best correspond to the stress-strain state of asphalt concrete in the pavement structure. These are methods for determining rutting.

Our results, in contrast to [15], have been confirmed by the study of various grain compositions within the boundaries of coarse-grained dense asphalt concretes of type A1, which makes it possible to confirm the reliability of such results.

Standard compaction of asphalt concrete under laboratory conditions using the pressing method does not allow predicting the properties of asphalt concrete in pavement layers. This leads to the need to make urgent changes to DSTU B B.2.7–319, DSTU B B.2.7–119 and other regulatory documents, which prescribe the methods of compacting asphalt concrete samples under laboratory conditions. The lack of determination of the physical and mechanical characteristics of asphalt concrete depending on the number of gyrations may be considered a drawback of this study.

In our study, coarse-grained asphalt concretes of type A1 were chosen, which can be considered a limitation because fine-grained asphalt concretes are used as road pavement layers in most cases.

In the future, it is necessary to consider the influence of compaction methods on the physical and mechanical properties of such asphalt concrete. In addition, it is necessary to adapt the system for determining the amount of compaction load application (the number of gyrations) to the conditions of Ukraine.

7. Conclusions

1. A comparison of water saturation and void content indicators produced using different compaction methods shows that the water saturation indicator used in regulatory documents of Ukraine almost always meets the requirements. But the indicator of void content in most cases during the manufacture of samples by gyratory compaction and industrial compaction does not meet the modern requirements of regulatory documents of Ukraine and the world. This indicates the imperfection of using the method of compaction by pressing and the indicator of water saturation for assessing the quality of asphalt concrete. In addition, when using the pressing method under laboratory conditions for the production of asphalt concrete samples to obtain the reference density index and subsequent calculation of the compaction coefficient, in most cases a compaction coefficient greater than 1 is obtained. This indicates a higher density of asphalt concrete during industrial compaction than during laboratory compaction. That is, the properties of asphalt concrete produced by pressing do not correspond to those obtained during compaction with a gyrator and production compaction. In addition, coarse-grained asphalt concretes used in Ukraine have too dense grain compositions and require correction in regulatory documents.

2. Compressive strength indicators are not sensitive to the method of compaction and are almost independent of it. The assessment of the resistance of asphalt concrete to the influence of elevated temperatures based on the strength indicator at 50 °C is incorrect and needs to be changed to the rutting resistance indicator.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Hu, W., Jia, X., Huang, B., Park, H. (2017). Evaluation of compactability of asphalt mixture utilizing asphalt vibratory compactor. Construction and Building Materials, 139, 419–429. https://doi.org/10.1016/j.conbuildmat.2017.02.070
2. Tarefder, R. A., Ahmad, M. (2016). Effect of compaction procedure on air void structure of asphalt concrete. Measurement, 90, 151–157. https://doi.org/10.1016/j.measurement.2016.04.054
3. Huber, G. History of asphalt mix design in North America, Part 1. Available at: http://asphaltmagazine.com/history-of-asphalt-mix-design-in-north-america-part-1/
4. EN 12697-30:2018. Bituminous mixtures – Test methods – Part 30: Specimen preparation by impact compactor. Available at: https://standards.iteh.ai/catalog/standards/cen/9728dcfe-4137-454b-8765-63a37932df62/en-12697-30-2018
5. ASTM D6926-04. Standard Practice for Preparation of Bituminous Specimens using Marshall Apparatus.
6. Duriez, M., Arrambide, J. (1964). Nouveaux traite des materiaux des constructions. Vol. 3. Paris: Dunod, 1543.
7. Zhdaniuk, V., Volovyk, O., Kostin, D., Lisovin, S. (2021). An investigation of the effect of thermoplastic additives in asphalt concrete mixtures on the properties of different types of asphalt concrete. Eastern-European Journal of Enterprise Technologies, 2 (6 (110)), 61–70. https://doi.org/10.15587/1729-4061.2021.227806
8. Pyrig, Y., Galkin, A., Oksak, S., Ilin, I., Shyika, Y. (2022). Influence of Rejuvenator on the Properties of Bitumen and Asphalt Concrete. Key Engineering Materials, 938, 225–233. https://doi.org/10.4028/p-b11x6t
9. Tipton, R. A. (1993). A study of California kneading compactors ability to optimise angular aggregate particle orientation and interlock of large stone asphalt mixes in Montana. Montana State University. Available at: https://studylib.net/doc/13510379/a-study-of-california-kneading-compactors-ability-to-opti
10. Abo-Qudais, S., Qudah, M. (2007). Effect of compaction method on bituminous mixtures voids distribution and magnitude. Advanced Characterisation of Pavement and Soil Engineering Materials – Proceedings of the International Conference on Advanced Characterisation of Pavement and Soil Engineering Materials, 817–829. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84858063707&partnerID=40&md5=40ae17f7e7e9176c66547ee641cddb97
11. Harman, T., Bukowski, J. R., Moutier, F., Huber, G., McGennis, R. (2002). History and Future Challenges of Gyratory Compaction: 1939 to 2001. Transportation Research Record: Journal of the Transportation Research Board, 1789 (1), 200–207. https://doi.org/10.3141/1789-22
12. Development and Performance Prediction of Idaho Superpave Mixes (2004). National Institute for Advanced Transportation Technology. Available at: https://www.webpages.uidaho.edu/niatt/research/Final_Reports/KLK464-N06-08.pdf
13. Bi, Y., Huang, J., Pei, J., Zhang, J., Guo, F., Li, R. (2021). Compaction characteristics assessment of Hot-Mix asphalt mixture using Superpave gyratory compaction and Stribeck curve method. Construction and Building Materials, 285, 122874. https://doi.org/10.1016/j.conbuildmat.2021.122874
14. EN 12697-31:2019. Bituminous mixtures - Test methods - Part 31: Specimen preparation by gyratory compactor. Available at: https://standards.iteh.ai/catalog/standards/cen/ab0e065c-37a0-4f6e-8f6e-e7465859eaa1/en-12697-31-2019
15. Oliveira, M. F., Bessa, I. S., Vasconcelos, R. R., Vasconcelos, K. L., Bernucci, L. L. B. (2021). A new approach to laboratory roller compaction method and its influence on surface texture and permanent deformation of asphalt mixtures. International Journal of Pavement Engineering, 23 (11), 3867–3878. https://doi.org/10.1080/10298436.2021.1924377
16. Doyle, J. D., Howard, I. L. (2011). Linear Asphalt Compactor. Operator's manual. Oak Ridge National Laboratory.
17. Muniandy, R., Jakarni, F. M., Hassim, S., Mahmud, A. R. (2007). Development of Criteria for Slab Compaction of Laboratory Roller Compactor (Turamesin). American Journal of Applied Sciences, 4 (11), 908–911. https://doi.org/10.3844/ajassp.2007.908.911
18. Bijleveld, F. R., Miller, S. R., de Bondt, A. H., Dorée, A. G. (2015). Aligning laboratory and field compaction practices for asphalt – the influence of compaction temperature on mechanical properties. International Journal of Pavement Engineering, 17 (8), 727–740. https://doi.org/10.1080/10298436.2015.1019494

19. Zhao, X., Niu, D., Zhang, P., Niu, Y., Xia, H., Liu, P. (2022). Macro-meso multiscale analysis of asphalt concrete in different laboratory compaction methods and field compaction. Construction and Building Materials, 361, 129607. https://doi.org/10.1016/j.conbuildmat.2022.129607
20. EN 12697-33:2003+A1:2007. Bituminous mixtures – Test methods for hot mix asphalt – Part 33: Specimen prepared by roller compactor. Available at: https://standards.iteh.ai/catalog/standards/cen/8c67ff09-b50c-4a37-bdb5-3ac26b6fcf4a/en-12697-33-2003a1-2007
21. Mozghovyi, V. V., Onyshchenko, A. M., Olkhovyi, B. Y., Oproshchenko, I. O., Kutsman, O. M., Baran, S. A., Riznichenko, O. S. (2016). The assessment of durability of asphalt pavement asphalt through the test for resistance to permanent deformation accumulation. Visnyk Natsionalnoho transportnoho universytetu, 34, 283–293. Available at: http://publications.ntu.edu.ua/visnyk/34_2016/283-293.pdf
22. Zolotaryov, V., Ilin, Y., Kipnis, D., Ekimov, V. (2022). The problem of optimizing laboratory compaction of asphalt concrete mixtures. Avtoshliakhovyk Ukrayiny, 2 (270), 47–55. https://doi.org/10.33868/0365-8392-2022-2-270-47-55
23. EN 12697-22:2020. Bituminous mixtures – Test methods – Part 22: Wheel tracking. Available at: https://standards.iteh.ai/catalog/standards/cen/4442b66e-a324-4503-880a-ee4342064693/en-12697-22-2020