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EXPERIMENTAL STUDY ON THE FATIGUE CRACKING RESISTANCE OF ASPHALT CONCRETE PAVEMENT REINFORCED WITH SYNTHETIC MESHES

This study investigates fatigue cracking resistance of asphalt concrete pavement beam specimens operating under cyclic loading conditions and undergoing fatigue cracking. The task is to establish the regularities of fatigue cracking resistance of asphalt concrete beam specimens reinforced with Adfors GlasGrid GG50, Adfors GlasGrid GG100, and Adfors GlasGrid CG50L geogrids.

Fatigue cracking resistance of asphalt concrete beam specimens reinforced with Adfors GlasGrid geogrids under the action of sinusoidal loading with a frequency of 10 Hz was examined experimentally.

The four-point bending method was accepted as the criterion for assessing fatigue durability when testing reinforced asphalt concrete beam specimens. Under the action of cyclic loading, the number of load application cycles was adopted, during which the initial complex modulus of rigidity that is observed after the first 100 load cycles would decrease by 50%.

It was found that when reinforcing asphalt concrete beam specimens with Adfors GlasGrid GG50 geogrid, the average number of cycles to lose 50% of the complex modulus of rigidity reached 68,460 load cycles during the application of loads. When reinforcing with Adfors GlasGrid GG100 geogrid, 76,900 load cycles, and when reinforcing asphalt concrete beam specimens with Adfors GlasGrid CG50L geogrid, 153,127 load cycles were applied. In the absence of asphalt concrete reinforcement with geogrids, the average number of load cycles was 25,975 cycles.

When losing 50% of the complex modulus of rigidity, it was found that the increase in the number of cycles in relation to beam specimens without geogrid reinforcement was 2.6 times when reinforcing beam specimens with Adfors GlasGrid GG50 geogrids. When reinforced with Adfors GlasGrid GG100 geogrids, this indicator was 3.0, and when reinforced with Adfors GlasGrid CG50L geogrids, it was 5.9

Keywords: asphalt concrete, fatigue cracking, Adfors GlasGrid geogrids, highways, cyclic loads

Artur Onyshchenko
Doctor of Technical Sciences, Professor**
Vitalii Kovalchuk
Corresponding author
Doctor of Technical Sciences, Professor*
E-mail: kovalchuk.diit@gmail.com
Oleksii Rykovtsev
PhD Student**
Oleg Tsekhansky
Head of Direction***
Dmytro Husev
Director***
Dmitry Anishchenko
Deputy General Director for Financial and Economic Issues
Municipal Corporation "Kyivavtodor"
Petra Bolbochana str., 6, Kyiv, Ukraine, 01104
Ivan Kravets
Doctor of Philosophy (PhD), Associate Professor*
Roman Lisnevskyi
PhD Student**
Olexiy Zagorodniy
PhD Student**
*Department of Railway Transport
Lviv Polytechnic National University
S. Bandery str., 12, Lviv, Ukraine, 79013
**Department of Bridges and Tunnels and Hydrotechnical Structures
National Transport University
Mykhaila Omelianovycha-Pavlenka str., 1, Kyiv, Ukraine, 01010
***Caponier-Group LLC
O. Honchara str., 57-B, Kyiv, Ukraine, 01054

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1. Introduction

Asphalt concrete that is used on highways is made of non-rigid road beds [1]. During asphalt concrete operation, defects and damage are formed. In addition to the formation of rutting, pits, and delamination of asphalt concrete layers, fatigue cracks appear [2, 3]. Such defects arise as a result of cyclic loads on asphalt concrete from motor vehicles. Eventually, the material structure damages and fatigue cracking of asphalt concrete occurs (Fig. 1), which leads to a limitation of the durability and performance of road surfaces.

Under operational conditions, cracks of a thermal and fatigue nature are often encountered. The mechanism of evolution and formation of fatigue cracks in asphalt concrete is characterized by the gradual destruction of the asphalt concrete surface under the action of repeated loads that exceed the endurance limit of the material [4, 5]. At the initial stage, microcracks are formed, which, with further loading, expand and turn into macrocracks. Macrocracks spread from the lower layers of the asphalt concrete surface to the surface, forming a characteristic network of fatigue cracks.

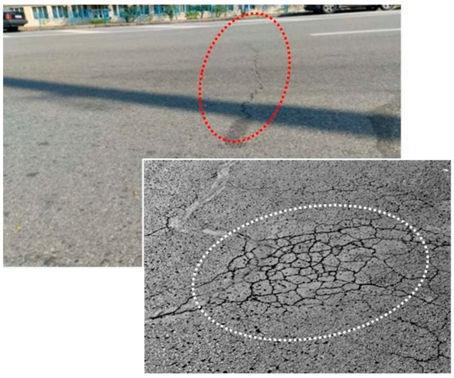

Fig. 1. Cracks in asphalt concrete pavement

The evolution of fatigue cracking of asphalt concrete is influenced by the intensity of loads from vehicles, temperature and humidity conditions of operation, the condition of the road surface bases, the type and composition of asphalt concrete mixtures.

When fatigue cracks are formed in asphalt concrete, the structural strength of the road surface decreases, moisture penetrates into the layers of the road surface. Peeling and potholes emerge, thereby accelerating the destruction of the entire road surface. As a result, the repair interval is sharply shortened and operating costs increase.

To ensure the durability of the asphalt concrete pavement under operational conditions, polymer-modified bitumen binders are used, which increase the elasticity of the material [6], as well as reinforcing meshes [7]. It is noted in [8] that devising effective solutions to prevent the evolution of transverse cracks and rutting in asphalt concrete is an urgent task of scientific research. When a crack propagates, the integrity of the road surface is disrupted, which leads to a significant decrease in the bearing capacity of the asphalt concrete pavement of highways. There is also an increase in the magnitude of the stresses in the base and soil layers of the roadbed. Therefore, one of the current areas of scientific research is experimental studies on the effectiveness of using synthetic meshes (geogrids) to enable resistance to fatigue cracking of the asphalt concrete pavement under the action of cyclic fatigue loads.

2. Literature review and problem statement

It was established in [6] that one of the reasons for the reduction of the residual resource of asphalt concrete pavement on reinforced concrete road bridges is the limited use of polymers to regulate the properties of asphalt concrete. The results of the studies showed that the arrangement of asphalt concrete pavement with improved properties, owing to the use of polymer latex, could increase its residual resource. This, in turn, would contribute to reducing the costs of repair and maintenance not only of the asphalt concrete pavement but also of the bridge structure as a whole. However, the authors did not conduct studies on the influence of geosynthetic meshes on the resistance to cracking of asphalt concrete pavement on highways.

The results of experimental studies reported in paper [7] showed that the reinforcement of asphalt concrete pavement with synthetic meshes such as GlasGrid®GG100 reduces rutting. It was found that at 10,000 load cycles and a temperature of 50°C, the average rut depth in the slab samples without a reinforcing mesh was 3.8 mm, and at a temperature of 60°C – 3.7 mm. In the case of reinforcing the top layer with a GlasGrid®GG100 mesh, the rut depth at an operating temperature of 50°C was 3.3 mm, and at an operating temperature of 60°C – 2.6 mm. It has been proven that reinforcing the top layer of the asphalt concrete surface with synthetic mesh could lead to an increase in the durability of the road sections of highways. However, the authors did not conduct studies on the influence of synthetic meshes on the resistance to fatigue cracking of the asphalt concrete surface under the action of cyclic loads.

The issues of crack resistance of road surfaces are considered in [9]. Modified bitumen is used to increase crack resistance. Studies have shown the effectiveness of using modified bitumen to improve the performance and durability of asphalt. Studies on the effectiveness of using modified bitumen are also confirmed in [10]. It shows the effectiveness of modified bitumen in increasing the rutting resistance and crack resistance of asphalt concrete pavement. However, papers [9, 10] do not investigate the effect of reinforcing meshes on ensuring the resistance of asphalt concrete pavement to fatigue cracking.

In [11] it was established that the cause of rutting on highways is the increase in traffic intensity and loads from vehicles. In this case, with insufficient stability of the asphalt concrete surface of the non-rigid road surface to the formation of ruts, the strength of the structure decreases. In addition, this affects the quality of adhesion of the road surface to the base [12]. However, in [11, 12] there are no studies of the influence of reinforcing road asphalt concrete surfaces with synthetic meshes on the crack resistance of asphalt concrete.

In [13], the authors emphasized the need to consider the interaction of reinforcing synthetic materials with the structures of adjacent zones of asphalt concrete layers, which exhibit the properties of reinforced asphalt concrete. It is proposed that the design characteristics be determined exclusively experimentally for each type of asphalt concrete structure and a specific type of reinforcing synthetic material.

In [14] it is established that only for the upper and middle layers of the asphalt concrete surface, the age of operation has a significant effect on crack resistance. The distance between transverse cracks can be used as a direct indicator for assessing the crack resistance of an asphalt concrete layer.

In [15], studies were conducted to design an optimal cold asphalt concrete mixture that could be used for ultra-thin asphalt concrete layers. A cold ultra-thin asphalt concrete layer GT-10 C was designed, which has similar or even better crack resistance indicators than conventional hot mixtures. This is achieved by using a high-performance binder, basalt fibers, and a specially selected grain composition of aggregates. It was found that GT-10 C has a higher ultimate tensile strength, impact and fracture toughness, as well as a longer time to crack formation compared to Hot-UA and Cold-UA.

Paper [16] reports the results of experimental studies based on the interpretation of an accelerated full-scale fatigue test of asphalt concrete, as well as numerical analysis of this experiment using the theory of linear-plastic fracture mechanics and Paris's law. To better control the process of crack formation during the fatigue test, a defect was artificially created (a metal angle was installed) in the lower part of the asphalt concrete layers, in the transverse direction to the moving load, which localized the crack initiation site. However, the authors did not conduct studies on the influence of reinforcement with synthetic meshes on the crack resistance of the asphalt concrete pavement.

In [17], recycled concrete aggregates (RCAs) obtained by crushing dismantled concrete structures from construction and demolition waste (C&DW) were added to assess the behavior of crack propagation in asphalt concrete pavements. As a result of experimental tests, it was found that the zones prone to crack formation are located in the areas of cement mortar adjacent to RCA, as well as at the bond boundaries between RCA and bituminous binder, which emphasizes the need for RCA strengthening treatment. It is found that the average crack propagation rate of AM-RCA increases by more than 7.3%, and the cracking strength decreases by more than 3.9%. This indicates that AM-RCA is more prone to cracking than asphalt concrete mixtures on natural aggregates (AM-NA).

In [18], the crack resistance of asphalt concrete pavements in service at moderate temperatures was evaluated using a large number of cores collected in Jiangsu Province, China. According to the results from analysis of variance (ANOVA), the service life of the pavement in the upper layer has the greatest influence on crack resistance. The fastest decrease in crack resistance with age is observed in areas with an average level of traffic intensity that have been in service for more than 14 years. It was also found that in the lower layer, the only significant factor affecting crack resistance was the air pore content. In general, with increasing layer depth, the influence of traffic load and pavement age decreases, while the influence of asphalt material properties increases. However, the effect of synthetic reinforcing meshes on the crack resistance of asphalt concrete was not investigated in the cited work.

In [19], the results of a laboratory study were reported, in which hot mix asphalt concrete (HMA) with the addition of recycled asphalt concrete (RAP) sieved through sieve No. 4 was used. The study investigated a typical top (surface) mixture with a RAP content of 0%, 10%, 20%, and 30%. Two types of mineral aggregates were used in the study – limestone and gravel, as well as three types of bituminous binders – PG 64-22, PG 70-22, and PG 76-22. The results of the study showed that the addition of RAP generally leads to an increase in stiffness and indirect tensile strength but reduces the crack resistance of the studied mixtures. It was found that the properties of the mixtures change significantly at a 30% RAP content, compared to the options with 10% and 20%.

Our review of the literature [6–19] demonstrates that most studies consider the effectiveness of using modified bitumen to reduce rutting and increase crack resistance of asphalt concrete pavements. However, such methods do not fully solve the task of increasing the resistance of asphalt concrete pavements to fatigue cracking under cyclic loads from vehicles. One promising method for increasing the resistance to fatigue cracking of asphalt concrete pavements is to use reinforced self-adhesive geogrids Adfors GlasGrid. However, there are no experimental studies that would allow us to assess the effectiveness of using geogrids to increase the crack resistance of asphalt concrete pavements. This does not allow for a targeted and effective influence on increasing the crack resistance of asphalt concrete pavements on highways under operational conditions. Therefore, an unsolved problem is the experimental assessment of the effectiveness of using self-adhesive geogrids Adfors GlasGrid to increase the resistance of asphalt concrete pavements to fatigue cracking under cyclic loads from vehicles.

3. The aim and objectives of the study

The aim of our work is to determine the influence of Adfors GlasGrid geogrids on the ability to improve the fatigue cracking resistance of asphalt concrete pavements of highways under cyclic loads. This will allow us to determine the effectiveness of using self-adhesive Adfors GlasGrid geogrids for reinforcing asphalt concrete pavements of highways in order to increase the fatigue cracking resistance of asphalt concrete under operational conditions.

To achieve this aim, the following objectives were accomplished:

– to devise a methodology for experimental testing of reinforced asphalt concrete pavements for fatigue cracking resistance;

– to analyze the results of experimental testing of reinforced asphalt concrete pavements with Adfors GlasGrid geogrids for fatigue cracking resistance.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study is the fatigue cracking resistance of asphalt concrete pavement beam specimens operating under cyclic loading conditions and undergoing fatigue cracking.

The principal hypothesis of the research assumes that experimental studies of asphalt concrete pavement beam specimens reinforced with Adfors GlasGrid geogrids and without reinforcement of beam specimens could make it possible to establish the fatigue cracking resistance of asphalt concrete. It is assumed that geogrids are included in the joint work of asphalt concrete under the action of cyclic loads from vehicles and increase the resistance of asphalt concrete to cracking. It is believed that the greater the number of load cycles the reinforced asphalt concrete withstood when the complex modulus of rigidity drops by 50%, the greater the fatigue durability of the reinforced beam specimen material.

4. 2. Synthetic materials GlasGrid for reinforcing asphalt concrete

To conduct research on the effect of Adfors GlasGrid geogrids on increasing the resistance to fatigue cracking in reinforced asphalt concrete, experimental tests were conducted in four stages. In the first stage, asphalt concrete beam specimens without geogrid reinforcement were tested. In the second stage, asphalt concrete beam specimens were reinforced with the synthetic material GlasGrid®GG50 (Fig. 2).

GlasGrid® GG50 is a self-adhesive, high-strength grid with a rigid structure of E-glass fibers [20]. It is coated with an elastomeric polymer and a self-adhesive pressure-activated bottom layer with a tensile strength of 55 × 55 ± 5 kN/m and a maximum elongation of 2.5 ± 0.5% [20].

In the third stage, experimental studies of asphalt concrete beam specimens reinforced with the synthetic material GlasGrid® GG100 were carried out (Fig. 3).

GlasGrid® GG100 is a self-adhesive, high-strength grid with a rigid E-glass fiber structure. It is coated with an elastomeric polymer and a pressure-activated self-adhesive bottom layer with a tensile strength of 115 × 115 ± 15 kN/m and a maximum elongation of 2.5 ± 0.5% [20].

In the fourth stage, the asphalt concrete beam specimens were reinforced with the synthetic material GlasGrid® CG50L (Fig. 4).

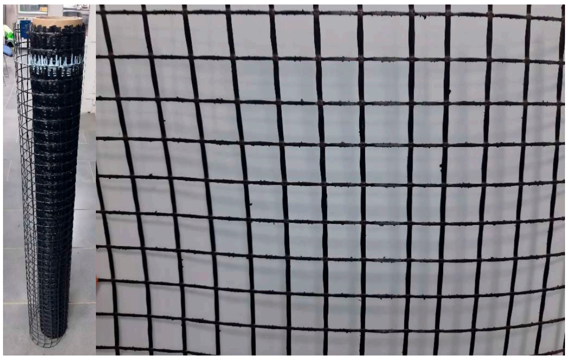

Fig. 2. Reinforcing synthetic material GlasGrid® GG50

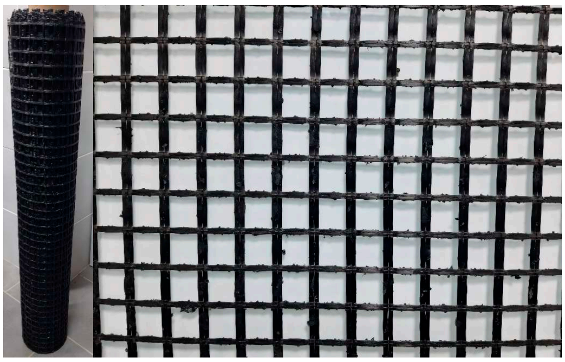

Fig. 3. Reinforcing synthetic material GlasGrid® GG100

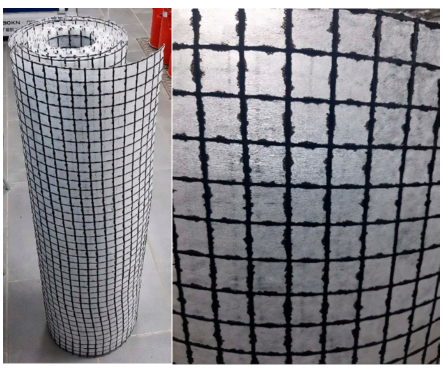

Fig. 4. Reinforcing synthetic material GlasGrid® CG50L

GlasGrid® CG50L is a composite material consisting of a high-strength E-glass fiber grid coated with an elastomeric polymer and a nonwoven textile layer, with a tensile strength of 55 × 55 ± 5 kN/m and a maximum elongation of 2.5 ± 0.5% [20].

4. 3. Fabrication of reinforced asphalt concrete beam specimens

For fabricating beam specimens, an asphalt concrete mixture of type A with a maximum grain size of 20 mm was used, applying road viscous bitumen of the BND 70/100 brand in accordance with DSTU B V.2.7-119.

Before the formation of beam specimens, the dynamic viscosity of the organic binder used in the mixture was determined using a Brookfield rotational viscometer in accordance with DSTU EN 13302:2019; the optimal heating temperatures were selected during the manufacture and compaction of the mixture. Fig. 5 shows the process of forming asphalt concrete beam specimens.

The upper layer was arranged after the manufacture, cooling, cutting (imitation of cracks) of the lower layer and laying on it, according to the technology and laying instructions, the appropriate reinforcing synthetic material. The upper layer was arranged without heating the roller compactor mold. The average density of the compacted material was 2.44 g/cm^3, the residual porosity was 3.2%, which complies with the standards of DSTU B V.2.7-119.

The average density of the samples was determined by forming test samples for the upper and lower layers with the calculated weight of the material. Further calculation was carried out in accordance with DSTU EN 12697-6:2019. The thickness of the top layer was 4.0 cm for tests according to DSTU EN 12697-22, EN 12697-48:2018, and 5.0 cm for tests according to DSTU EN 12697-24, DSTU B V.2.7-319.

The application of the binding emulsion was carried out before laying the geogrid. Bitumen emulsion EKSH-60 (cationic fast-decomposing emulsion with a bitumen content of 60%) was used as the binding emulsion.

The dosage of the emulsion consumption for the reinforcing materials GlasGrid® GG50 and GlasGrid® GG100 was 0.3 kg/m^2, and for GlasGrid® CG50L – 0.6 kg/m^2 of the residual amount of bitumen. Before laying the top layer of asphalt concrete, the moment when the binding emulsion completely disintegrated was expected.

To activate the adhesive of the self-adhesive reinforcing synthetic material, two passes of the roller compactor were performed, followed by a check for adhesion (about 2 kg per sample, at the rate of at least 5 kg/m^2).

Fig. 5. The process of molding asphalt concrete beam specimens

5. Results of experimental studies on the fatigue cracking resistance of reinforced asphalt concrete pavement

5. 1. Methodology of experimental testing of fatigue cracking resistance of asphalt concrete beam specimens reinforced

The methodology of experimental testing of beam specimens of asphalt concrete pavement reinforced with geogrids provided for a four-point bending test. For this purpose, prismatic beam specimens were manufactured (Fig. 6).

The geometric dimensions of the beam specimens (width *B* and height *H*) were 60 mm. At the same time, the height of the upper layer was 40 mm, the lower layer was 20 mm. The length of the specimens was 360 mm. This ratio was adopted from the calculation that the reinforcing synthetic material was in the stretched zone of the beam specimen when applying load cycles to the beam specimens reinforced with geogrid. When applying load cycles to the unreinforced beam specimens, a crack in the lower layer was present in the stretched zone.

The beam specimens were tested on a servo-hydraulic dynamic testing system DTS-30 from Matest (Italy). The system is shown in Fig. 7.

Fig. 6. Beam specimen for four-point bending tests

Fig. 7. DTS-30 servo-hydraulic dynamic testing system

The test temperature was +20°C since fatigue cracks are considered the main problem at a temperature of +20°C. The temperature-setting of the samples was carried out for 2 hours.

The beam samples were fixed in the loading frame using external and internal clamps (Fig. 8).

The beam specimens then start to move with a given sinusoidal frequency of 10 Hz. The necessary force is applied through the device's loading frame connected to both internal clamps. The type of loading (constant deflection) is provided by means of feedback of the measured displacement. The level of microstrains is set to 200 μ_ε, which is determined by two factors: the need to provide about 10,000 loading cycles before the initial stiffness decreases to 50% and the time constraints of the experimental tests.

To study the fatigue crack resistance of beam specimens of reinforced asphalt concrete pavement, the method developed by Van Dijk and Visser was used. It is characterized by the fact that it determines the number of loading cycles (N_f) at which the complex modulus of stiffness of the specimen decreases to 50% of its initial value. The initial value is defined as the stiffness at the 100th loading cycle.

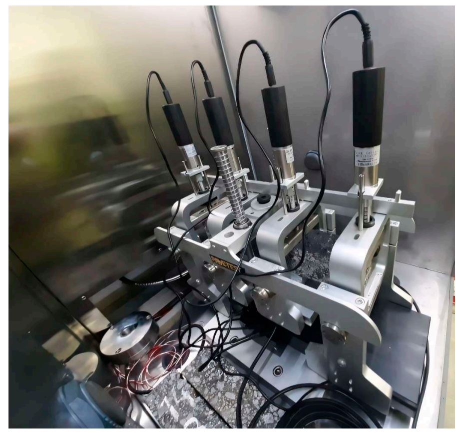

Fig. 8. Sample beam in a dynamic testing device

5. 2. Results of experimental tests of asphalt concrete pavement reinforced with synthetic meshes for resistance to fatigue cracking

The plots of the drop in complex modulus of rigidity for 50% of asphalt concrete pavement beam specimens under the action of a sinusoidal load with a frequency of 10 Hz are shown in Fig. 9–12.

From Fig. 9 it is seen that 50% drop in the complex modulus of rigidity for the beam specimen without reinforcement with synthetic meshes was 26,070 loading cycles. With the initial value of the complex modulus of rigidity of 2,993.7 MPa, the final value of the complex modulus of rigidity was 1,496.4 MPa, which corresponds to a 50% drop in rigidity.

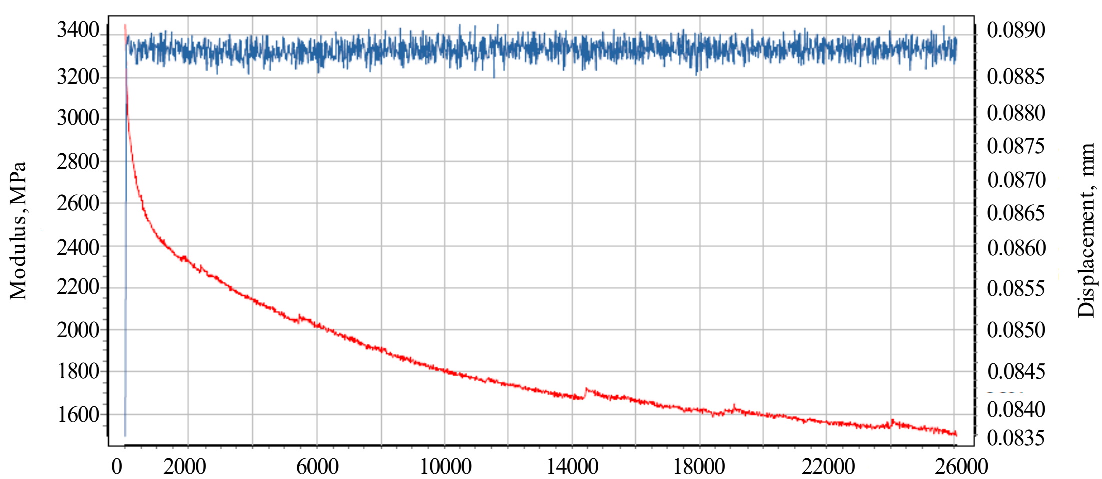

Fig. 9. Plot of the drop in the complex modulus of rigidity by 50% for beam specimens of asphalt concrete pavement without reinforcement with reinforcing synthetic material

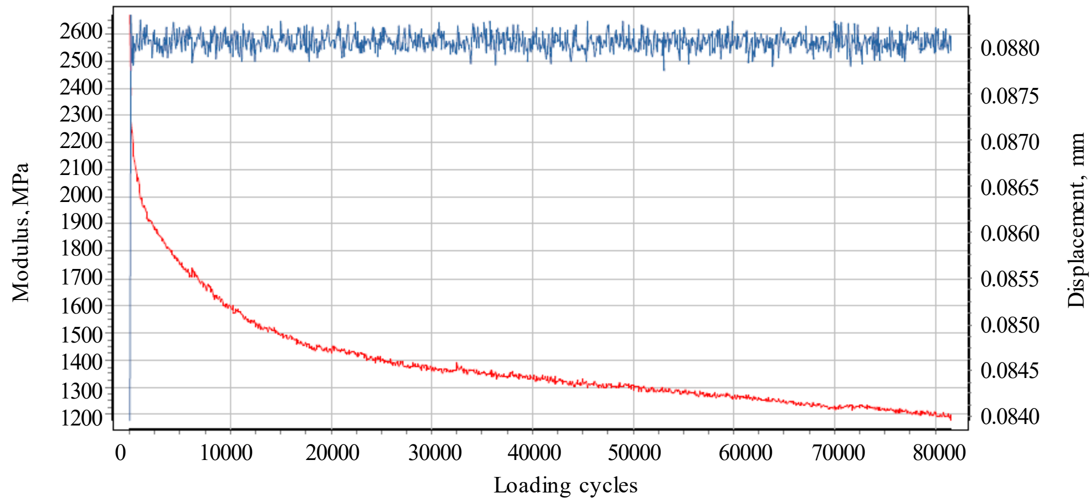

Fig. 10. Plot of the drop in the complex modulus of rigidity by 50% for asphalt concrete pavement beam specimens reinforced with synthetic material, self-adhesive geogrid Adfors GlasGrid GG50

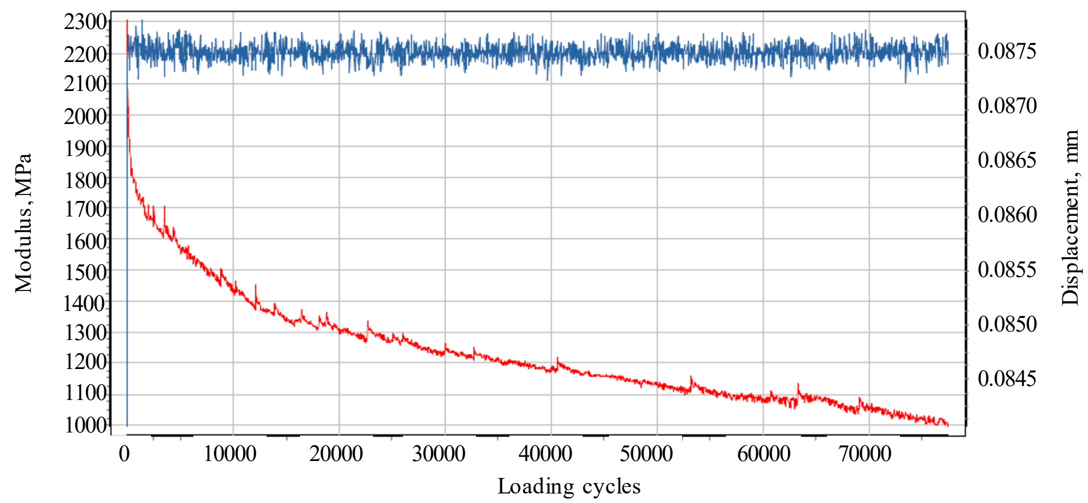

Fig. 11. Plot of the drop in the complex modulus of rigidity by 50% for asphalt concrete pavement beam specimens reinforced with synthetic material, self-adhesive geogrid Adfors GlasGrid GG100

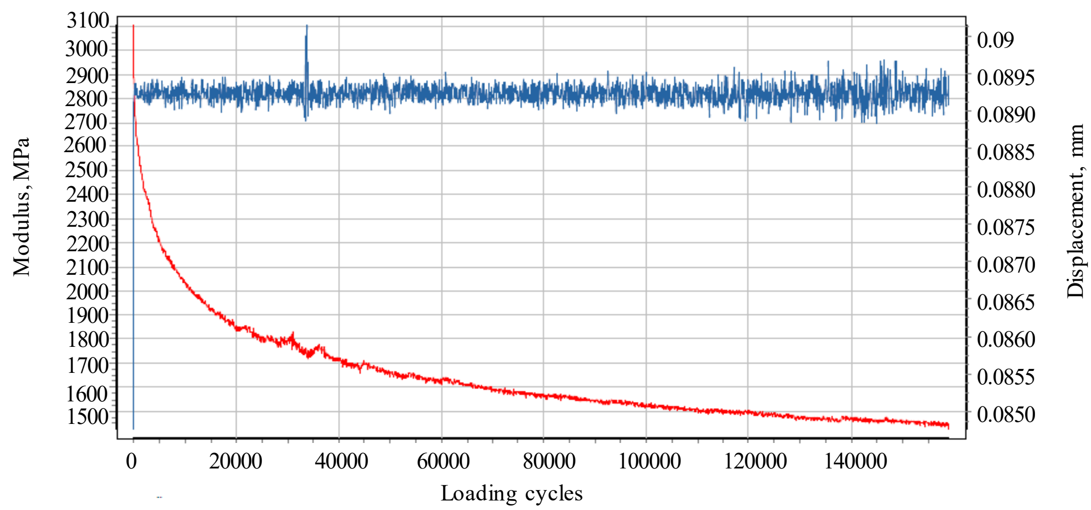

Fig. 12. Plot of the drop in the complex modulus of rigidity by 50% for asphalt concrete pavement beam specimens reinforced with synthetic material, geogrid with Adfors GlasGrid CG50L substrate

In the case of reinforcing asphalt concrete beam specimens with Adfors GlasGrid GG50 self-adhesive geogrid (Fig. 10), the 50% drop in the complex modulus of rigidity for the beam specimen was 81,570 loading cycles. With an initial value of the complex modulus of rigidity of 2,360.7 MPa, the final value of the complex modulus of rigidity was 1,176.5 MPa, which corresponds to a 50% drop in rigidity.

The results of experimental studies showed that when reinforcing asphalt concrete beam specimens with self-adhesive geogrid Adfors GlasGrid GG100 (Fig. 11), the 50% drop in the complex modulus of rigidity for the beam specimen was 77,500 loading cycles. With an initial value of the complex modulus of rigidity of 1,993.1 MPa, the final value of the complex modulus of rigidity was 996.0 MPa, which corresponds to a 50% drop in rigidity.

The results of experimental studies showed that when reinforcing asphalt concrete beam specimens of asphalt concrete pavement with synthetic material, geogrid with Adfors GlasGrid CG50L substrate (Fig. 12), the 50% drop in the complex modulus of rigidity for the beam specimen was 159,000 load cycles. In this case, the initial value of the complex modulus of rigidity was 2,853.2 MPa, and the final value of the complex modulus of rigidity was 1,426.5 MPa, which corresponds to a 50% drop in rigidity.

According to the results of multivariate experimental tests, the average values of the number of load cycles of the beam specimens of asphalt concrete pavement reinforced with Adfors GlasGrid geogrids were obtained, at which a 50% decrease in the complex modulus of rigidity occurs. The results of the studies are given in Table 1.

According to the test results of beam specimens reinforced with Adfors GlasGrid reinforcing synthetic materials, it was found that reinforced specimens have significantly better results in terms of fatigue cracking compared to specimens without reinforcement. In particular, the increase in the number of cycles until 50% loss of the complex modulus of rigidity in relation to the specimen without reinforcement with reinforcing synthetic material is 2.6 times for beam specimens reinforced with reinforcing synthetic material, self-adhesive geogrid Adfors GlasGrid GG50; 3 times for beam specimens reinforced with reinforcing synthetic material, self-adhesive geogrid Adfors GlasGrid GG100; 5.9 times for beam specimens reinforced with reinforcing synthetic material, geogrid with Adfors GlasGrid CG50L backing.

Thus, reinforcing the asphalt concrete pavement with Adfors GlasGrid reinforcing synthetic materials makes it possible to increase the number of loading cycles until the loss of 50% of the complex modulus of rigidity by 2.6–5.9 times (i.e., by 160–490%) compared to the unreinforced asphalt concrete pavement.

Table 1

Results of four-point bending tests of reinforced asphalt concrete pavement beam specimens

Material description	Initial complex modulus of rigidity, MPa	Ultimate complex modulus of rigidity, MPa	Number of load cycles	Average number of load cycles
Beam specimens without synthetic material reinforcement	2,993.7	1,496.4	26,070	25,975
	2,695.9	1,347.5	25,880	
Beam specimens reinforced with synthetic material, Adfors GlasGrid GG50 self-adhesive geogrid	2,360.7	1,176.5	81,570	68,460
	2,289.8	1,140.2	64,870	
	2,258.0	1,125.9	58,940	
Beam specimens reinforced with synthetic material, Adfors GlasGrid GG100 self-adhesive geogrid	1,993.1	996.0	77,500	76,900
	2,475.6	1,237.6	76,300	
Beam specimens reinforced with synthetic material, geogrid with Adfors GlasGrid CG50L backing	2,853.2	1,426.5	159,000	153,127
	1,836.5	917.1	142,910	
	2,073.5	1,034.6	157,470	

Our results make it possible to confirm the effectiveness of using Adfors GlasGrid reinforcing synthetic materials under the top layer of the asphalt concrete pavement. They make it possible to significantly increase the fatigue resistance and fatigue durability of the asphalt concrete pavement.

6. Discussion of the results of research on the fatigue cracking resistance of asphalt concrete pavement reinforced with synthetic meshes

Experimental studies on the influence of reinforcement of asphalt concrete samples with Adfors GlasGrid geogrids allowed us to determine the regularities of fatigue failure (Table 1), which was often observed during visual inspection of Ukrainian roads (Fig. 1). This became possible with the entry into force of DSTU EN 12697-24:2018, which made it possible to obtain reliable information on the regularities of changes in the fatigue durability of the material depending on the characteristics of loading and temperature effects. This allows us to select the composition of the asphalt concrete mixture taking into account the predicted number of loading cycles, thereby identifying ways to increase the fatigue durability of asphalt concrete pavements and ensure their reliable operation in road structures during the estimated service life.

The methodology of experimental studies of beam specimens reinforced with asphalt concrete pavement for fatigue crack resistance involves determining the number of load cycles at which the complex modulus of rigidity of the sample decreases to 50% of its initial value.

The employed four-point bending method with sinusoidal loading (Fig. 8) is relatively simple but has certain limitations. The number of cycles at which the initial value of the complex modulus of rigidity is estimated can be affected by nonlinearity [21, 22]. In addition, the fracture of the specimen can occur before reaching a 50% reduction in the complex modulus of rigidity, the specimen can break [23]. The reduced value of the complex modulus of rigidity can be achieved after the occurrence of a crack in the specimen. However, this approach has been used in many studies [24, 25].

The results of experimental studies (Fig. 9–12, Table 1) showed that when reinforcing asphalt concrete pavement with reinforcing synthetic materials Adfors GlasGrid, the number of loading cycles increases until 50% of the complex modulus of rigidity is lost. The number of cycles increases by 2.6–5.9 times (i.e., by 160–490%) compared to unreinforced asphalt concrete pavement.

Our experimental results (Table 1) confirm the results of the studies reported in [26]. They also correspond to the results of studies by the University of Parma and field experiments on the IFFSTAR ring stand (France) on the test ring of the National Center for Asphalt Technologies (NCAT) at Auburn University in Alabama, USA [27, 28]. According to the results of the research, it is stated that the reinforcement of asphalt concrete pavement with reinforcing synthetic materials Adfors GlasGrid increases its crack resistance and durability by no less than three times.

The results obtained are an increase in the number of cycles until the loss of fifty percent of the complex modulus of rigidity in relation to the beam sample without reinforcement. It has been established that the use of reinforcing synthetic materials Adfors GlasGrid under the top layer of asphalt concrete pavement makes it possible to significantly increase the fatigue resistance to cracking and increase the fatigue durability of the asphalt concrete pavement. This is due to the inclusion of synthetic materials Adfors GlasGrid in joint work with asphalt concrete during the action of loads.

The practical significance of our results is in the effectiveness of using Adfors GlasGrid self-adhesive geogrids in reinforcing asphalt concrete. This will provide increased fatigue resistance and increase the fatigue durability of asphalt concrete pavement under road operation conditions.

One of the limitations of the current study is that the accuracy of this method has not yet been established. However, this is still the only standardized method for assessing the fatigue resistance of asphalt concrete pavements. The disadvantage of the research is the limited number of tested beam specimens, because of limited resources, and, at this stage, their number is the minimum permissible. It is necessary to continue further testing with a larger series of samples. The effectiveness of using Adfors GlasGrid materials in general has a positive trend in their use in reinforcing asphalt concrete pavement. Adfors GlasGrid materials make it possible to improve the resistance to fatigue cracking of asphalt concrete pavement.

Another area of subsequent scientific research is to determine the influence of reinforcement of asphalt concrete specimens on determining the ultimate bending strength.

7. Conclusions

1. The methodology of experimental testing for fatigue cracking resistance of asphalt concrete beam specimens reinforced involves conducting four-point bending tests under sinusoidal loading. The criterion for fatigue durability in four-point bending tests under loading cycles is the number of load application cycles during which the initial modulus of rigidity, which is observed after the first 100 cycles, will drop by 50%. The greater the number of load cycles a reinforced asphalt concrete specimen withstands, the greater the fatigue durability of the material of this specimen. In our study, an unreinforced asphalt concrete specimen was the control.

2. The results of our experimental tests of reinforced asphalt concrete samples with Adfors GlasGrid geogrids showed that the average number of load cycles in beam samples reinforced with Adfors GlasGrid GG50 geogrid was 68,460 cycles. In the case of Adfors GlasGrid GG100 geogrids, the number of cycles was 76,900, and when using geogrids with Adfors GlasGrid CG50L substrate, the number was 153,127 cycles. At the same time, in asphalt concrete beam samples without reinforcement, the average number of cycles was 25,975 cycles.

According to the results of our research, it was found that the increase in the number of cycles until the loss of fifty percent of the complex modulus of rigidity in relation to the beam specimen without reinforcement with reinforcing synthetic material is as follows:

– specimens reinforced with reinforcing synthetic material with self-adhesive geogrid Adfors GlasGrid GG50 – by 2.6 times;

– specimens reinforced with reinforcing synthetic material with self-adhesive geogrid Adfors GlasGrid GG100 – by 3 times;

– specimens reinforced with reinforcing synthetic material with geogrid with substrate Adfors GlasGrid CG50L – by 5.9 times.

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, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

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

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Authors’ contributions

Artur Onyshchenko: Conceptualization, Project administration; **Vitalii Kovalchuk**: Methodology, Validation; **Oleksii Rykovtsev:** Investigation; **Oleg Tsekhansky:** Methodology, Resources; **Dmytro Husev**: Investigation; **Dmitry Anishchenko:** Investigation; **Ivan Kravets:** Visualization; **Roman Lisnevskyi:** Investigation; **Olexiy Zagorodniy:** Visualization.

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