Geosynthetic Reinforced Interlayers Application in Road Construction

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Abstract. The article is devoted to the analysis of theoretical and experimental data of the geosynthetic layers reinforcing functions and their functional interaction with other layers in the top dressing structure. The materials and results are presented in accordance with the basis of a project on a highway section reconstruction by means of geosynthetics. An optimal method for solving the main problem in road construction, being the impact of negative external factors causing the destruction of the pavement structure is studied in the paper. The essence of the method is impregnation of the synthetic material with a binding solution, in this case, a bitumen emulsion, which will ensure its good adhesion to asphalt concrete. Results of the study: The theoretical and experimental data of geosynthetic layers reinforcing functions and their functional interaction with other layers in the structure of road covering were analyzed. The materials and results found on the basis of highway section reconstruction project with the use of geosynthetics are presented. Given the current trends in the road construction providing for the optimization of all processes in order to improve their operational properties and achieve maximum economic efficiency of the decisions made, the research on geosynthetic materials is relevant today.

Keywords: Geosynthetics · Technologies · Construction · Road surface covering · Geosynthetic layers · Geotextiles

1 Introduction

The rapid increase in the number of heavy road transport, increase in traffic intensity and, as a result, increase in axial loading of the road surface contribute to developing deformations of asphalt concrete roads based on conventional bitumen. The main problem here is the deformation of road pavements. Bitumen can no longer fully satisfy today's requirements. All over the world, work is constantly being carried out to create new modern road materials and technologies, to adjust the regulatory requirements to their physical and mechanical properties. This is aimed at increasing the road pavement durability in modern operating conditions. The main task is to analyze the road technology construction using geosynthetic layers, to review their characteristics, identify disadvantages and advantages.

V. Murgul and V. Pukhkal (Eds.): EMMFT 2019, AISC 1258, pp. 94–103, 2021.
https://doi.org/10.1007/978-3-030-57450-5_9

Nowadays, non-rigid road surfacing with asphalt concrete layers predominates on the highways of Ukraine, as well as in the whole world. Such road dressing is often quickly destroyed by transport loads and requires early repairs.

Destruction is manifested depending on the loading conditions and nature. Cracks are a quite common type of destruction of asphalt concrete layers. That's why, in recent years, increase the durability of such layers, reinforcing interlayers in the form of synthetic materials are widely used in practice. Though, their application is not sufficiently supported by a theoretical base that would allow to calculate the asphalt concrete layers of road dressing taking into account the specificity of reinforcing synthetic materials operation.

In recent decades, many scientific works of domestic and foreign scientists have been devoted to investigation of the fracture resistance of asphalt concrete layers, but not enough attention has been paid to the study of the reinforcing synthetic layers effect on the overall stress and strain state of these layers.

So, there are practically no theoretical papers in this field that would allow to develop a single computing technique for asphalt concrete layers reinforced with synthetic materials. It is known that road-construction materials and road bed soils exhibit viscous-elastic properties under loading, which must be taken into account when determining the stress and strain state of road dressing reinforced asphalt concrete layers under the action of transport loads and in assessing their limiting state.

The interaction of asphalt concrete as a material with a synthetic layer is a complex process that requires a careful study in the process of theoretical and practical research.

Review of recent publications on the topic: geosynthetic materials in road construction are reviewed and analyzed according to national standards (DSTU EN 14030: 2006, SOU 45.2-00018112-025: 2007, VBN B.2.3-218-544: 2008, supplement to VBN B.2.3-218-544: 2008, EN 12224, P B.2.3-218-21476215-795: 2011); national [1–7] and foreign publications [8, 9].

2 Materials and Methods

Application of reinforcing materials in highways designing, construction, reconstruction and repair. In recent years, structures using tens of thousands of geotextile materials have become widespread throughout the world, and systematic surveys indicate their high reliability, durability and technical and operational indices. Geotextile material is being increasingly used in the ground bed construction and road covering though, the specifics of its work in road covering is less studied than in the ground bed.

A number of foreign publications are devoted to the issue of road dressing reinforcement, describing the experience of construction of road structures including the "asphalt concrete - reinforcing layer – asphalt concrete" structural elements. Geotextile, fiberglass, various polymeric nets, metal gauzes and metal pins are used as layers [2].

Research and observation results have shown that geotextile enhances the drainage properties and has reinforcing effect, thereby slowing down the process of pavement fracturing.

Geosynthetics are extensively used to strengthen and monitor the development of cracks in road surfaces in Australia, Belgium, Canada, Italy, Spain, Slovenia, The Netherlands, Czech Republic, Germany, France [2].

Geotextiles make it possible to limit and reduce fracturing of the asphalt concrete covering. It is necessary to use low-compressible geotextile materials that do not increase the pavement deformation under loading and are not too rigid. They must be compatible with bitumen and heat-resistant in the temperature range of laying the asphalt concrete mixtures.

From this review we can conclude that:

- the use of geotextile interlayers in or between the road dressing structural layers and the conditions of their joint work are of great practical importance for road construction;
- geotextile used for reinforcement of road structures has now become an independent construction material, which in many cases cannot be replaced by a traditional material;
- reinforcement of road dressing structural layers with geotextile materials allows to increase their strength, to prevent of formation of broken cracks in covering asphalt concrete layers, to reduce the materials consumption of the road structure;
- data of systematic reinforced structure surveys indicate their reliability, durability and high technical and operational performance;
- layered road structures increase the culture of production, by reducing the production cycle, technological effectiveness of operations and their quality indices.

The main types of synthetic materials and their general characteristics.

It is relevant to consider the classification of geosynthetic materials according to the British methodology, which is designed to review, analyze and systematize specific samples. This classification, shown in Table 1, is essential in the process of selecting rational types of road structures, depending on the desired properties, engineering and geological, soil and climatic conditions.

The area, efficiency and feasibility of using synthetic rolled materials (SM) are determined by their properties, depending on the composition of the raw material and production technology. To manufacture SM different polymers are used: polyamide (PA), polyester (PET), polyether (PETh), polypropylene (PP), polyethylene (PE) and others (Table 2). Mixtures of polypropylene and polyethylene are referred to as polyolefins. Additives may be added to get special properties. Polyvinyl chloride (PVC), polyethylene, bitumen are used as coatings.

The properties of non-woven geotextiles depend on the method of strengthening the road bed:

- mechanical (needle-punching) – material, anisotropic in two mutually perpendicular directions, differs in low tensile strength, permeability and high deformability;
- chemical - hardening is achieved by putting in binding glue into the material, which fixes the fibers at the points of contact;
- thermal - the road bed is heat-calendered with fibers sintering.

Table 1. Classification of geosynthetic materials.

Name	Material, polymer	The area of application	Physico-mechanical indices
Non-woven: needle punched, thermally bonded	Polypropylene	Substrate for composites, anti-clogging and reducing filtration properties, for arranging drainage structures and separating layers	Tensile strength, load-bearing capacity, relative elongation for nominal strength, modulus of elasticity, resistance to light and exposure to chemical agents, porosity
Knitted and woven	Polyester and propylene	Reinforcement of bases belonging to the category of weak, slopes with steepness above average value, retaining walls	Relative elongation for strength and tensile strength. Chemical resistance and light resistance. Modulus of elasticity, flowability boundary and cone puncture strength
Geogrids: - woven, - Extrusive	Polypropylene, glass, polyamide, polyester, polyethylene	Reinforcement: Ground and natural foundations, arrangement of rigid and flexible piles, pileworks, reinforcement of asphalt coverings	Relative elongation for strength, modulus of elasticity, creep deformation, resistance to light, density, external friction coefficient
Bulk geogrates: - modular, - Gabion grid, - honeycomb	Polypropylene	Reinforcement of slopes, cones and embankments. Reinforcement of foundations of increased steepness slopes	Tensile strength, frost resistance and resistance to chemical effect
Compositional: - porous, - fibrous - multilayer with plastic frame and protective layers, non-woven low density materials	Polypropylene, polyethylene, polyester	Strengthening of slopes and arrangement of drainage in places with difficult geological and climatic conditions	Moisture and water resistance, relative deformation and tensile strength
Geomembranes	Polypropylene and polyethylene	Reduction of active stresses by reducing friction with soil components	Water tightness, elongation at rupture. Ultimate strength, thickness, material density

(*continued*)

Table 1. (*continued*)

Name	Material, polymer	The area of application	Physico-mechanical indices
Dampproof material	Polypropylene and bentonite	Arrangement of completely waterproof elements	Protection against adverse effects of the aquatic environment

Table 2. Fibers used for manufacturing synthetic materials.

Index	Fiber-forming polymers			
	Polyester, polyether	Polypropylene	Polyamide	Polyethylene
Density, g/cm	1.36–1.38	0.90–0.92	1.14	0.95–0.96
Water absorption, at 21 °C and relative humidity 65%	0.2–0.5	0	3.5–4.5	0
Fracture tensile strength, MPa	35–90	22–55	45–70	32–65
Elongation at rupture, %	15–40	15–30	30–80	15–30
Creeping ability	Insignificant	High	Insignificant	Very high

3 Results

Due to the structure thus formed, SM has excellent water permeability and high tensile and fracture strength characteristics. Thermo-bonded SMs are characterized by high marginal elongation (up to 70%) and increased durability.

Secondary raw materials, including those containing non-synthetic components, may be used to manufacture roadway SMs, provided that their properties meet the requirements. Depending on the manufacturing method, the SMs are divided into woven and non-woven. Woven SMs have a regular structure, high strength, high modulus of elasticity. But they do not have sufficient water permeability in the road bed plane. Such materials should be used in case the SM layers perform the functions of reinforcement, protection, but not drainage.

Asphalt concrete covering reinforcement polyester grids are used, having high strength and low deformation characteristics, chemical and biological stability, as well as good compatibility - adhesion to bitumen and heat resistance in the working temperatures range when laying asphalt concrete.

4 Discussion

Reinforcement of road asphalt concrete coverings. When applying reinforcing grids in road covering construction with asphalt concrete layers, no additional demands for structural layer materials are made; road-construction materials must meet the requirements of the State Standards of Ukraine.

Reinforcement of road asphalt concrete coverings is aimed at increasing the durability of road structure. It can be accomplished by introducing a reinforcing layer of woven or non-woven type, if their characteristics meet the requirements (Table 3).

Table 3. Requirements for reinforcing synthetic materials.

Surface density, g/m	Tensile strength at breaking, min. kN/m	Elongation, max, %	Melting point, °C
100–400	20	20	+180–200

When reinforcing the road covering asphalt concrete layers, the SM is placed directly under the asphalt concrete layer, which will be considered reinforced, that is, it will have increased strength and deformation properties as compared to conventional one. In this case, the reinforcing layer is placed only within the width of the roadway. At strengthening the asphalt concrete coverings with synthetic materials the minimum thickness of the asphalt concrete layer above the interlayer should be not less than 5 cm.

The number of asphalt concrete layers and their thickness is assigned depending on the required load bearing capacity of the road. When arranging two- and three-layer coverings, it is advisable to lay the reinforcing mesh to increase the fracturing resistance in the area of high tensile stresses.

Reinforcing grid is laid over the entire width of the roadway apon the existing covering or between the second and third layers of asphalt concrete, in the areas of concentrated high shear stresses:

- in places of intensive transport braking and at stops;
- under the top asphalt concrete layer.

During current repair of asphalt concrete covering, the reinforcing grid is used in places of irreversible deformations: cracks, subsidence, potholes, etc. The reinforcing grid is laid onto a leveled and binder treated surface. In case of a significant damage to the existing covering milling is applied. The existing covering layer is partially removed, increasing the thickness of the reinforcement layer over the damaged area to the depth of milling. The reinforcing grid is laid symmetrically with respect to the axis of the destroyed section or crack [8].

When reinforcing rigid foundations (cement concrete, layers treated with mineral binders) with asphalt concrete layers, the reinforcing grid is placed only over transverse and longitudinal cracks if the distance between cracks and joints is more than 3 m.

With the spacing between the transverse cracks less than 3 m, it is advisable to reinforce the asphalt concrete covering along the entire roadway width.

When the roadway is extended, there is a problem of ensuring the reliable joint work of the existing design having a formed structure and structural binding. The different nature of the designs operation causes new binding and a new construction, where the processes of deformation and consolidation have not yet been completed.

It is possible to reduce the amount of tangent stresses in the contact zone of the two structures by increasing the contact zone, creating a so-called leaning effect. It is recommended to reinforce the contact areas with synthetic grids to provide the fracturing resistance of the covering.

Methods of calculating the reinforced asphalt concrete covering of non-rigid road dressing for the strength under the action of vehicles.

Asphalt concrete covering is calculated for the fracture resistance to the transport action, as well as other monolithic layers under the current regulatory and technical document. According to this regulatory method, it is required that in monolithic layers of road dressing stresses resulting from the deflection under repeated short-term loading do not cause structural rupture of the material or fracturing, i.e. the condition

$$K_{mts} \leq \frac{R_{zg}}{\sigma_r} \quad (1)$$

must be ensured, where

K_{mts} is the strength factor, given the specified level of reliability;
R_{zg} are the maximum allowable tensile stresses of the layer material with regard to fatigue;
σ_r is the highest tensile stress in the layer calculated.

The asphalt concrete calculation characteristics, modulus of elasticity and fatigue ratio are determined at loading time of 0.1 s. and T - 0 °C. The allowable tensile stress is determined by the dynamic flexural strength test at a strain rate of 100 mm/min.

Thus, according to the current calculation method, only one type of loading mode at a time of 0.1 s is used, when only the tensile stresses in the lower part of the covering are taken into account when it is bent by the action of the transport estimated load, transmitted in the form of a distributed vertical load over the area of the circle, equidimensional to the wheel imprint.

According to the national normative document for the reinforced asphalt concrete layers the following condition must be fulfilled

$$K_{mts} \leq \frac{k_{cf}^{a} \cdot R_{zg}}{\sigma_r} \quad (2)$$

where, K_{mts}, R_{zg}, σ_r are the values given in the above formula;

k_{ef}^{a} is the reinforcement efficiency coefficient determined by a special methodology.

An analysis of the world experience in the construction and operation of road surfacing with layers increasing the fracturing resistance and strength of asphalt concrete pavements shows that the layers can be divided into two groups: "soft" and "stiff". Each group has a particularity in the mechanism of their impact on road covering fracturing resistance and performance [7].

The choice of the strength theory and the criterion of the local boundary condition is usually somewhat conventional. The theory of determining the stress-strain state must correspond to the experimentally obtained characteristics of the materials.

Several strength theories are currently used to predict asphalt pavement fracturing. Some theories require special methods for determining the strength characteristics of materials; others use traditional characteristics or their modifications.

The determination of stress-strain state is carried out by means of the method of finite elements. The elements are prismatic, two-dimensional with the crack model, its environment included into the general model of the road pavement. This method takes into account the effect of annual changes in temperatures.

The methodology developed in SoyuzdorNII and KADI takes into account not only the effect of transport means and annual temperature fluctuations, but daily temperature fluctuations as well [7].

In setting the problem, the road top dressing is presented as an elastic multilayer package laid onto a rigid base. Given that the elasticity theory equation is considerably simplified when solving a plane problem, we have restricted ourselves to studying the plane deformation. But even with this approach, the boundary conditions reflecting the presence of a series of vertical rectangular sections in one of several layers, do not allow to solve the problem analytically. Therefore, we had to use also the method of finite elements. As a basis the isoparametric quadratic element was adopted, as it is the most effective in terms of accuracy and time of calculation.

When constructing a finite element grid, thickening was done to increase the accuracy of calculations near the vertices of the sections. In addition to the quadrangular elements triangular elements have been used. Depending on the material used as a layer, one of two calculation schemes was used. For example, geotextile was modeled by presenting it as an elastic thin layer, characterized with a thickness, a very low modulus of elasticity, and finite Poisson coefficient. The grid was modeled by a set of deformable elementary plates, interconnected by hinged joints. This approach takes into account the fact that the real grid layer does not perceive the compressive stresses in the horizontal direction. The model of a set of elementary plates is characterized by the modulus of elasticity obtained at stretching Poisson's ratio equal to 0, and thickness.

Given the reliability of the technique and a great experience in determining the tensile strength in bending, in the first phase of research, it was decided to evaluate the road asphalt pavement fracturing resistance by a stretch arising over the crack under the action of road transport. In this case, we may assume that the integrity of the covering will not be broken, if the tensile stress during repeated bending won't exceed the admissible limits for asphalt concrete established, taking into account the fatigue phenomena.

The thermal stressed state of the fracture-block covering was considered, given the asphalt concrete relaxation ability. At the same time, when evaluating the temperature stresses, the Volterr-Boltzmann ratio of linear viscosity and elasticity theory, and the principle of temperature-time analogy were used. As a result, the relationship between the nature of temperature fluctuations (daily and annual) and the degree of danger of temperature fracturing have been established and subsequently used. At the same time, And a simple method for experimental determination of the parameters of the road covering material long-term durability at different temperatures has been developed. To take into account the interlayers, their impact on the process of cracks formation when determining the long-term strength parameters, the composition "asphalt - reinforcing layer - fractured - block base (initiator of cracks)" has been researched.

5 Conclusion

Analysis of existing approaches to increasing the asphalt concrete layer stability by means of geosynthetic reinforcing layers has shown the disparity of current theoretical and experimental studies. So far, there has been no single technique optimally ensuring maximum results of the interaction and compatibility of road pavement materials and reinforcement layers.

The interaction of asphalt concrete as a material with a synthetic interlayer is a complex process that requires careful theoretical and practical research. These materials are completely different in the origin, composition and properties, which complicates the mechanism of their interaction. In the process of laying the asphalt concrete layer onto the interlayer, the "reinforcing layer - asphalt layer" system is made up and an inseparable contact between them is formed due to the adhesive ability of the asphalt binder and the mechanical adhesion and catching of the interlayer individual parts with the asphalt concrete mineral components. If geogrid is used as a reinforcing layer, its joints together with links work as anchors in asphalt concrete, being a support for coarse filler (crushed stone, gravel) [10].

The coupling of the reinforcing layer with asphalt concrete is provided by: the increase in asphalt concrete resistance to flexural stresses, caused by armature irregularities and periodic profile, i.e. mechanical adhesion of the reinforcing layer with asphalt concrete; formation of friction on the reinforcing layer surface due to its compression by the asphalt concrete during rolling; bonding of the asphalt concrete with the reinforcing interlayer due to the presence of bitumen [11].

When arranging a reinforced asphalt concrete layer during construction, the reinforcing interlayer comes into close contact with the asphalt concrete. But in the process of operation due to the action of various factors, at the points where the displacement of the interlayer relative to the asphalt layer is not possible (absolute contact) the area of contact is reduced as a result of partial separation of the reinforcing layer from the asphalt layer. Therefore, in this case it is possible to distinguish two contact areas:

- he area with absolute contact;
- he area where the displacement of the intermediate layer relative to the asphalt layer is possible.

Tensile stresses are transmitted from the asphalt concrete layer to the reinforcing layer only due to their mutual friction and mechanical adhesion. This case is characterized by the fact that between the interlayer and the asphalt layer there arise external friction forces, internal friction forces and accompanying friction, as well as the phenomenon of adhesion of macroscopic particles with the surface [11].

To ensure a reliable contact between the interlayer and the asphalt layer, it is necessary that the friction and adhesion forces are maximized. This is possible only under several conditions:

- the modulus of elasticity of the grid must not be lower than the asphalt concrete modulus;
- the size of the grid cells should be sufficient to allow the mixture to penetrate to ensure good catching and adhesion between the upper and lower layers of the covering (base);
- to transfer the tensile force, the grid adhesion with the asphalt concrete layer must be sufficiently strong;
- the grid material must have high temperature resistance without impairing its basic physical and mechanical characteristics.

An optimal method for solving the main problem in road construction has been investigated, namely, the impact of negative external factors contributing to the destruction of the road pavement design. The essence of the method is compulsory impregnation of the synthetic material with a binding solution, in this case, a bituminous emulsion, which will ensure its good adhesion with the asphalt concrete [11].

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