UDK 625.7./8;UDK 625.731.1

Gameliak I, Doctor of Engineering Science, Academic Advisor, Euroizol Geosynthetics , Kyiv, Ukraine
Dmitrenko L. Chief of laboratory ADBL «Textile-TEST» KNUTD, Kyiv, Ukraine
Zhurba G., Director, Euroizol Geosynthetics, Kiev, Ukraine

RESEARCH OF GRIDS' THERMAL STABILITY FOR REINFORCEMENT OF ASPHALT CONCRETE

Introduction

During road construction geogrids are widely used. They are aimed to act as strengthening and reinforcement [1 - 5], namely they:

1. Reduce the thickness of the layer, thus preserves natural resources and saves the environment.
2. Reduce the amount of work on the excavation, replacement and disposal of weak ground.
3. The opportunity of compaction of the necessary structural layers.
4. Increase of the exploitation terms of the pavement and overhaul service life.
5. Help to avoid uneven sagging on karst or mixed natural bases.
6. Prevent the manifestation of cracking in the asphalt concrete pavements arranged in block-fractured bases.

To ensure durability and service life prediction of geo-textile materials used in road and airfield construction it is necessary to know not only initial properties but change of characteristics during construction and exploitation.

Analysis of recent research and publications.

Effect of temperature on mechanical properties of different types of polymers, fibres and grids made of them is not researched enough. Despite the deviation of different fibres and grids made from the same fibres, there is a general tendency, which is the reduction of strength and elongation increasing as for discontinuous and continuous properties at raise of temperatures.

Distributors offer grids for reinforcement of soil and artificial basements as well as for reinforcement of asphalt concrete pavements. The quality of materials is characterized mainly by strength of geogrids and elongation at stretching. Practice has shown that such characteristics are not enough to assess the quality of geogrids in full. The cases of rapid destruction of roads by not taking into account of the heat-resistant properties of geogrids confirm this fact.

Problem statement

In accordance with international practices and the requirements of building standards for reinforcement of asphalt concrete pavements it is recommended to apply reinforcing synthetic materials (RSM) with strength of not less than 50 kN/m for roads of Ist and IInd category and not less than 40 kN / m for roads IIIrd and IVth category. With appropriate technical and economic justification RSM can be used with strength of more than 100 kN / m. To ensure the efficient use of RSM, its elongation in tension should not exceed the maximum elongation at break of composite (asphalt concrete and RSM) which is 6-12% subject to test temperature. The work of asphalt concrete pavement in elastic stage is provided with elongation of RSM within 2-5%.

In the process of road construction and laying of asphalt concrete mixture and compacting of asphalt concrete the geotextile materials are exposed to high temperatures and mechanical stress [4-6].

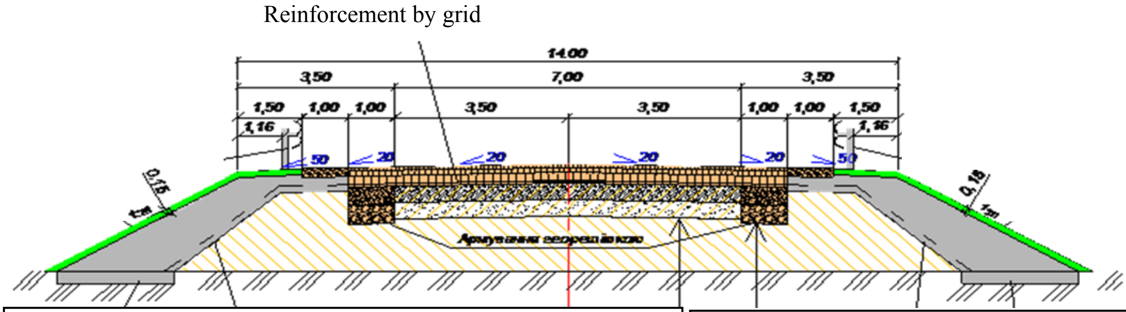
Suppliers of geosynthetic materials for the Ukrainian market provide characteristics such as strength, elongation and surface density. Practice has shown that these characteristics are not enough to assess the quality of geogrids in full. The cases of rapid destruction of roads by not taking into account of the thermal stability properties of geogrids and change of their linear characteristics during technological operations confirm this.

Experience of using polypropylene grids leads to the conclusion that due to the significant coefficient of linear expansion at heating of the layer of hot asphalt concrete there is a significant elongation of grid, that leads to their release surface pavements, and upon cooling reduction of linear dimensions happens causing internal stress and cracks in asphalt concrete layer.

For example, the destruction of construction on 175 km of the road Kipti - Glukhiv - Buchivsk shown in Fig.1, and can be seen on the pictures below (Fig. 2).

Reconstruction of the road consisted in rubblization of 22 cm cement concrete slab and installing the alignment layer. In areas with a weak basement disruption of slab wasn't carried, it was recommended to use a non-rigid reinforcing grids, to reduce the possibility of appearance of reflected cracks on concrete slabs joints. At the top of the levelling layer 10 cm layer of asphalt concrete was lined. The construction of area at 175 km has 6 cm pavement arranged with close-grained asphalt concrete placed over polypropylene grid with substrate over the subsoil made of bitumen emulsion. The grid was fixed by dowels to the surface frequently enough. All the works were carried out efficiently, according to the existing rules of reinforced pavement technology. The works were carried out in September of 2008.

At the beginning of hot period in mid-May 2009, at the bottom of the slope the first crack appeared. Disclosure of it was about 1.5 - 2 cm. In a couple of weeks, on the top of the 350 meters' area just over the border of grid laying a transverse crack occurred. On 7th of July 2009 year the gap's width of crack was about 20 cm. In the longitudinal direction in the middle and on the edge of the sidewalk appeared a crack of width 7 - 8 cm and asphalt concrete was sliding over the grid.
The quality of work on pavement arrangement was good and satisfactory. The only discrepancy upon construction was a longitudinal slope of 45 ppm, which is higher than recommended standards (30 ppm).



The design of pavement reinforcement:
- milling surface treatment;
- bitumen spills BND 90/130 (flow rate - 0.6 l / m^2);
- leveling layer is made of porous asphalt concrete of noncontiguous composition IInd type for under layers (AB. PD.Kr.P.PR. II according to DSTU B.V. 2.7-119-2003) , average thickness is 0,05 m;
- bitumen spills BND 90/130 (0,6 l/m^2);
-porous asphalt concrete of noncontiguous composition IInd type for under layers (AB. PD.Kr.P.PR. II according to DSTU B.V. 2.7-119-2003) , thickness is 0,10 m;
- bitumen spills BND 90/130 (0,3 l/m^2);
- dense fine grained asphalt concrete of type B of noncontiguous composition IInd type for bottom layers (A.B.NШ.Dr.Shch.B.NP. II, according to DSTU B.V. 2.7-119-2003), thickness is 0,06 m;
- bitumen spills BND 90/130 (0,3 l/m^2);
- stone mastic asphalt concrete (SMA-10 according to TU U 45.2-V.2.7-03450778-204-2002), thickness is 0,04 m.

Road pavement design for widening of traffic way (picture 1 on the left had side):
- basement bottom layer is made of crashed stone of type 800 – 1400 and grade 40 – 70 mm by jamming method, thickness is 0,15 m;
- basement is made of optimal macadam mixture C 5 reinforced with cement of type M40 (4% of cement) , thickness is 0,15 m;
- bitumen spills BDN 90/130, flow rate is 0,6 l/m^2;
- upper layer of basement is made of hot porous coarse grained asphalt concrete mixture of type II, thickness is 0,10 m;
- bitumen spills BND 901/30, outgo is 0,3 l/m^2;
- upper layer of pavement is made of stone mastic asphalt concrete mixture, thickness is 0,04 m.

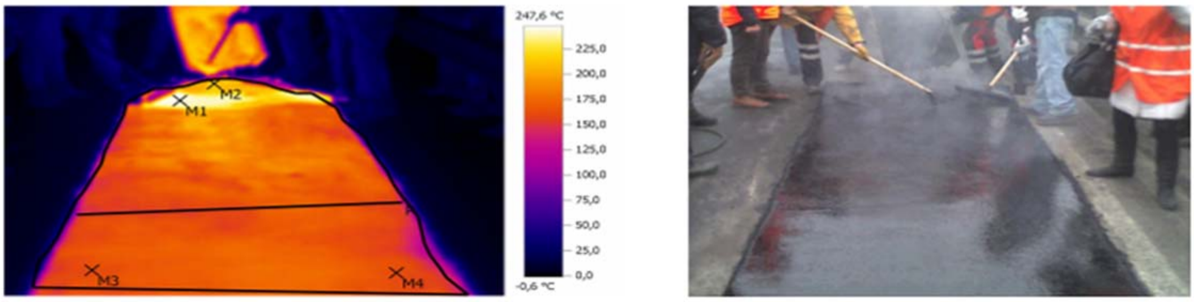
Fig. 1. Construction of pavement on the section

The main reason for separation between the pavement and the basement is grid deformation as a result of temperature. In contact with hot asphalt concrete grid heating took place resulting in linear dimensions change in material: heating led to uneven elongation and cooling to reducing the length (shrinkage).
After the disruption work on removal of pavements and grid were done and covering with new layer of layer-grained asphalt concrete and stone-mastic asphalt SMA-20 was made.
Research purpose is to determine the thermal stability of rigid and flexible geosynthetic grids of different raw composition by standard method and laboratory method simulating the conditions of thermal exposure on test samples at laying of asphalt concrete during road construction.

Justification of the research methods. Effect of temperature on operational characteristics of technical textiles is determined by GOST 29104.14-91 [7]. Its essence lies in determining the stability of the tested materials to high temperatures and comparing quality indicators before and after exposure of specified temperature on a material in the selected period of time. Test conditions do not simulate actual conditions of thermal effects on the geogrids when arranging pavements, therefore characteristics obtained by the standard method not fully correspond to the changes during actual use.
For simulation of temperature effects in laboratory conditions it was determined temperature fields allocations at the laying and cooling of asphalt concrete layers during the use of geogrids.
This allocation is determined by the thermal imager. The example of thermograms obtained during the repair of pavement on Pivdenny Bridge in Kyiv city on 22nd of November of 2012 is shown in Fig. 3. Monitoring of cooling of cast layers of asphalt concrete mixtures of different thicknesses (from 2 to 7 cm) revealed temperature dependence of the pavement surface to the cooling time.

Fig. 2. View of the section on the descent and disruption of asphalt concrete pavement in upper part of section.

As a result of thermal inspection of pavement on this and other objects dependence of the surface temperature to the cooling time of cast asphalt concrete mixture, stone-mastic asphalt and dense asphalt concrete of different thicknesses (from 2 to 10 cm) at ambient temperature 0 ... 35 ° C (Fig. 4) was obtained.



Histogram Profiles line

Min 20,3 ºC Max 247,6 ºC Average 169,2 ºC Min 126,4 ºC Max 174,3 ºC Average 160,0 ºC

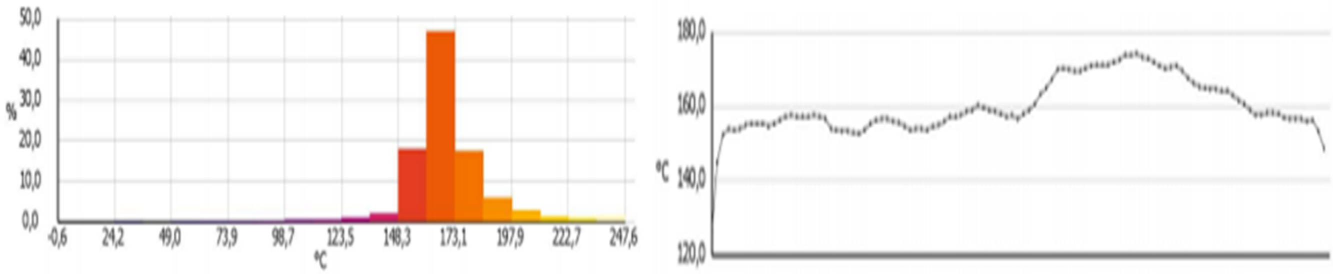


Fig. 3. Example of thermogram, pictures and results of processing at thermal imaging examination of repairing

process of pavement by cast asphalt conc

By results of researches it was received the theoretical dependence for calculation of cooling time t depending on and speed of asphalt layer cooling T_{AB} at variable temperature of mixture arrived to the building site

$$\boldsymbol{T}_{AB} = \exp(-(\frac{T_0-T_a}{h_0} \cdot (k_1 + k_2\sqrt[3]{(v_w-1)} - k_3 \cdot \sqrt{t} - k_4\sqrt{t} \cdot \sqrt{v_w - 1}) \cdot t), \quad (1)$$

where T_o is temperature of mixture and T_a is an ambient temperature, h_o is thickness of asphalt concrete layer, v_w - wind speed, k_1, k_2, k_3, k_4 - coefficients.

The obtained data is the basis for justification of temperature modes of geosynthetic samples withstanding in the laboratory to test on thermal stability.

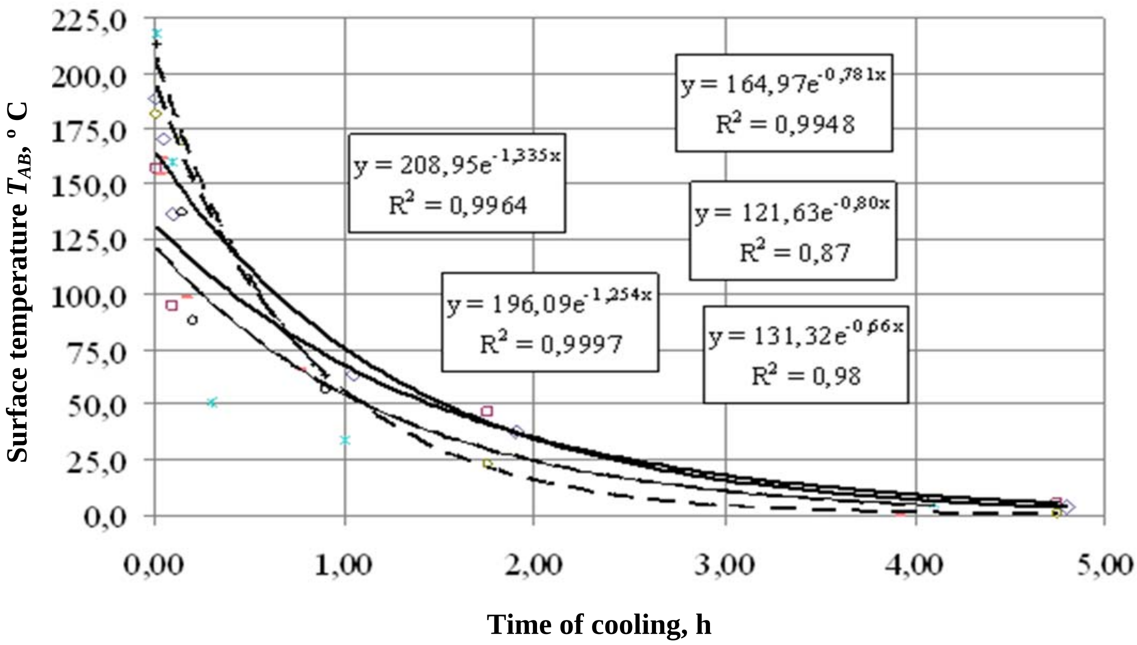


Fig. 4. Dependence of the pavement surface temperature to the cooling time of cast asphalt concrete mixture of different thicknesses from 2 to 7 cm

The objects of research. Characteristics of reinforcing geosynthetic materials for road construction adopted for the research are shown in Table. 1.

Table 1. Characteristics of reinforcing geosynthetic materials (RGM)

Index	Unit	Value				
Code			RGM 1	RGM 2	RGM 3	RGM 4
Raw materials structure			polyester	fibreglass	polyvinyl-alcohol	polypropylene
Size of cells	mm	MD	35+/-5	35+/-5	30+/-5	50+/-5
		CMD	35+/-5	35+/-5	45+/-5	50+/-5
Number ribs at 1 m in length and width	rib/m	MD CMD	22 22	24 24	25 20	16 18
Tensile tension, EN ISO 10319 and СОУ 45.2-00018112-025: 2007	кН/м	Average, MD	60	50	55	40
		Tolerance	-5	-	-5	-5
		Average, CMD	60	50	55	40
		Fault	-5	-	-5	-5
Relative deformation at maximum elongation, EN ISO 10319 and СОУ 45.2-00018112-025: 2007	%	MD	10	3	6	10
		Fault	+/-1,5	+/-0,5	+/-1,0	+/-1,5
		CMD	10	3	6	10
		Fault	+/-1,5	+/-0,5	+/-1,0	+/-1,5
Melting point	°C		250-260	8150	215-220	160-165

Rigid polypropylene geogrids were used. The number of longitudinal ribs is 16 rib/m, the number of lateral is 18 rib/m. Also it was researched the changes of physical and mechanical properties of reinforcing geosynthetic materials (RGM) under the influence of temperature effects and found thermal stability characteristics of geogrid made of polyester, polyvinyl-alcohol and glass fibres and polypropylene ribs.

Results and analysis

The experiment was conducted according to the following schedule.

- Determined thermal stability by standard methods.
- Determination of thermal stability in the laboratory, for this purpose the conditions of thermal effect on geogrids were created that are close to heat exposure during laying asphalt concrete in the construction of roads.

As a criteria of geogrids thermal stability the following was selected: changes in linear dimensions after heat exposure, changes in strength and elongation at stretching. According to the standard method geogrids were kept at thermal chamber for 2 hours at temperature = 160 ° C, then their characteristics were determined. Also tests were carried on thermal stability of geogrids in the chamber at t = 120 ° C and t = 100 ° C within 10 minutes. The results of thermal stability determination according to the standard method is given in Table. 2, and according to the proposed method in Table. 3 and 4.

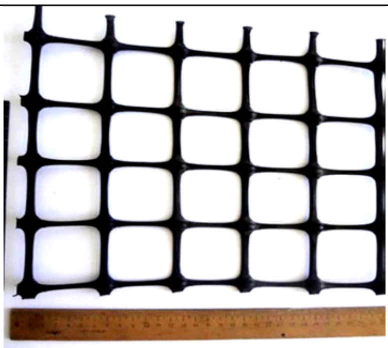
Table 2. Results of determination of geogrids thermal stability by the standard method

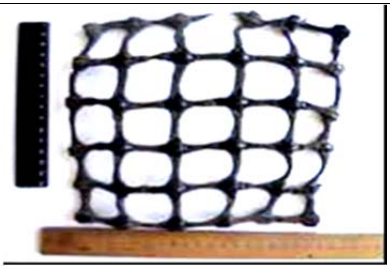
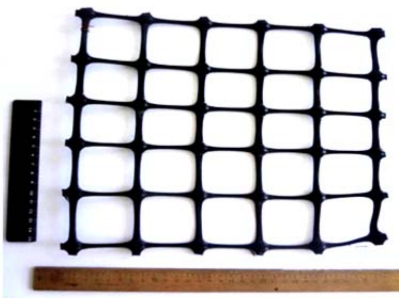
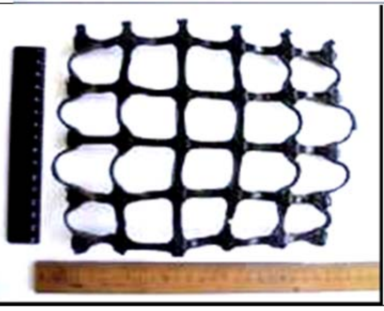
Name of indicators		Output data	After testing in thermal chamber		
			t=160 °C. for 2 hours.	t=120 °C. for 10 min	t=100 °C. for 10 min
Limit strength kN / m					
	By length	37	29,3	-	37,4
	By width	30	20,52	-	30,2
Elongation at marginal strength in %					
	By length	15,8	64,5	-	15,9
	By width	16,7	38	-	16,6
Tensile load by 5% kN / m					
	By length	25	-	-	24,9
	By width	13,2	-	-	13,1
Change of linear dimensions after heat exposure in %					
	By length	-	41,9	7,6	0
	By width	-	50	3,3	0

Following the testing data by the standard method, strength above length reduces by 20.8%, above width by 31.6%. Elongation at marginal strength changes even more increasing above length in 3.08 times and 1.28 times above width.

Test conditions, temperature conditions and grids behaviour after different test modes are given in Table. 3.

Table 3. Geogrid's appearance after testing in different temperature and loading conditions

Appearance after testing	Testing conditions	Temperature range
	1 – fixed with loading	Sand was heated up to 175 ºC .
	2 – non-fixed geogrid	Sand was heated up to 175 ºC and poured onto the grid. That moment grid was heated up to 101 ºC, in 2 minutes it was heated up to 138 ºC and then it started cooling. *Elongation in* length l= 6,3 %, in width l_l= 1,7%

	T_0= 205 ºC.	Sand was heated up to 205 ºC, poured onto the grid and at this moment the grid had temperature up to 130 ºC, in 2 minutes it had 142 ºC and then started cooling. E*longation in* length *l*= 36,9 %, in width l_l= 34,0% .
	4 – without loading	Sand was heated up to 198 ºC, poured onto the grid and at that moment the grid was heated up to122 ºC, in two minutes it was 173 ºC and then it started cooling.
	6 – without loading	Sand was heated up to 250 ºC. At the moment of grid filling up with sand, it was heated up to 193 ºC, in 2 minutes the temperature was 250 ºC.
	7 – without loading	After filling up with sand (sand was heated up to 208 ºC) the grid was deformed and shrunk, in the centre of sample, the arch appeared.

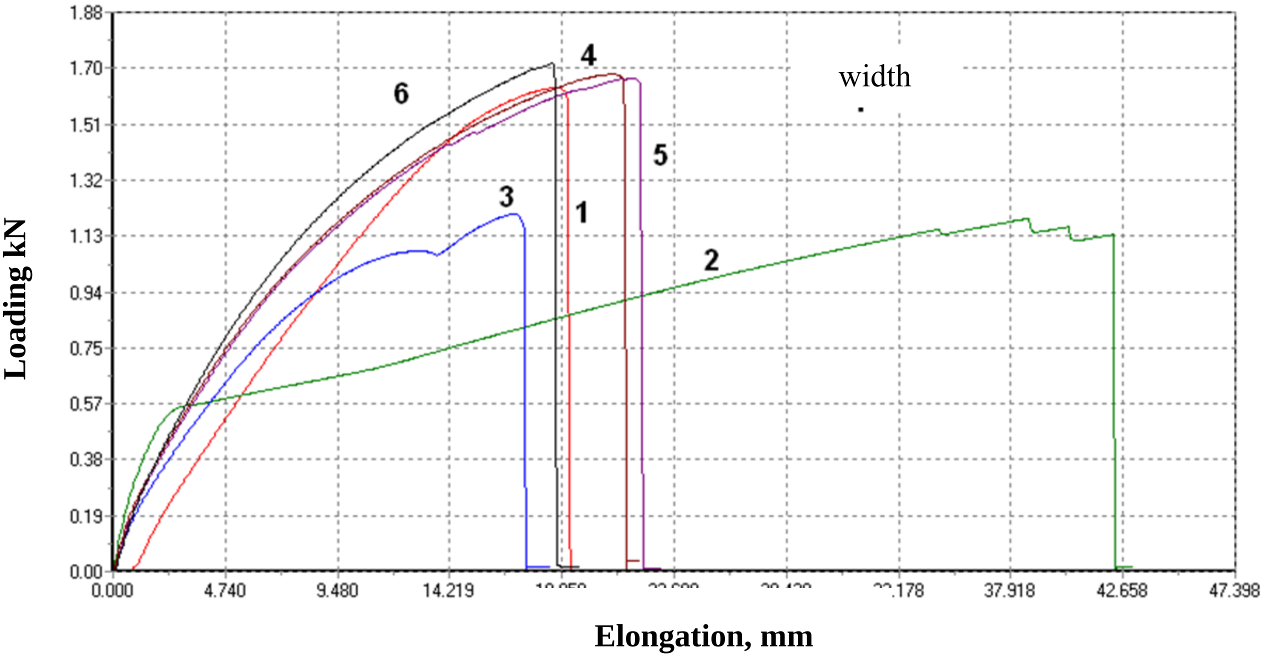
To create condition of thermal effect on grid in the time of laying of asphalt concrete in laboratory conditions the following research was carried:

- metal container with sand and metal plate, which was heated up to special temperature, was placed into heat chamber. Geogrids were placed into the wooden frame and fixed in each mesh at the frame bottom.
  Detectors were fixed to geogrids to determine heating temperature. After that geogrids were filled up with sand, heated to special temperature. Metal plate was placed on the top of that and over there loading units for simulation of asphalt concrete loading on grating in the time of laying. In the moment of contact with sand heating temperature of grid and its cooling temperature through time were fixed.
  It is given temperature change comparison from the time of sand cooling for some researches during grid testing and temperature change of covering surface subject to cooling of asphalt concrete mixture of different thicknesses from 2 to 7 cm.
  Temperature effect on rigid geogrid performances at elongation is given in a diagram “loading- elongation” at picture 5.
  For correct choice of geosynthetic material (GM) on thermal stability the following conditions should be met [7-8]:

$$T_{melting} \geq T_{laying} + \Delta, \text{ or } \quad T_{laying} \leq T_{melting} - \Delta,$$

where $T_{melting}$ is softening temperature of polymer, used for grid production, T_{laying} is temperature of the beginning of thickening subject to bitumen softening temperature, $T_{softening}$ for traditional asphalt concrete is

$T_{laying} = 92 + T_{softening,}$, here $T_{softening}$ is softening temperature of bitumen, Δ is reserve for temperature, 20 – 40 ºC.



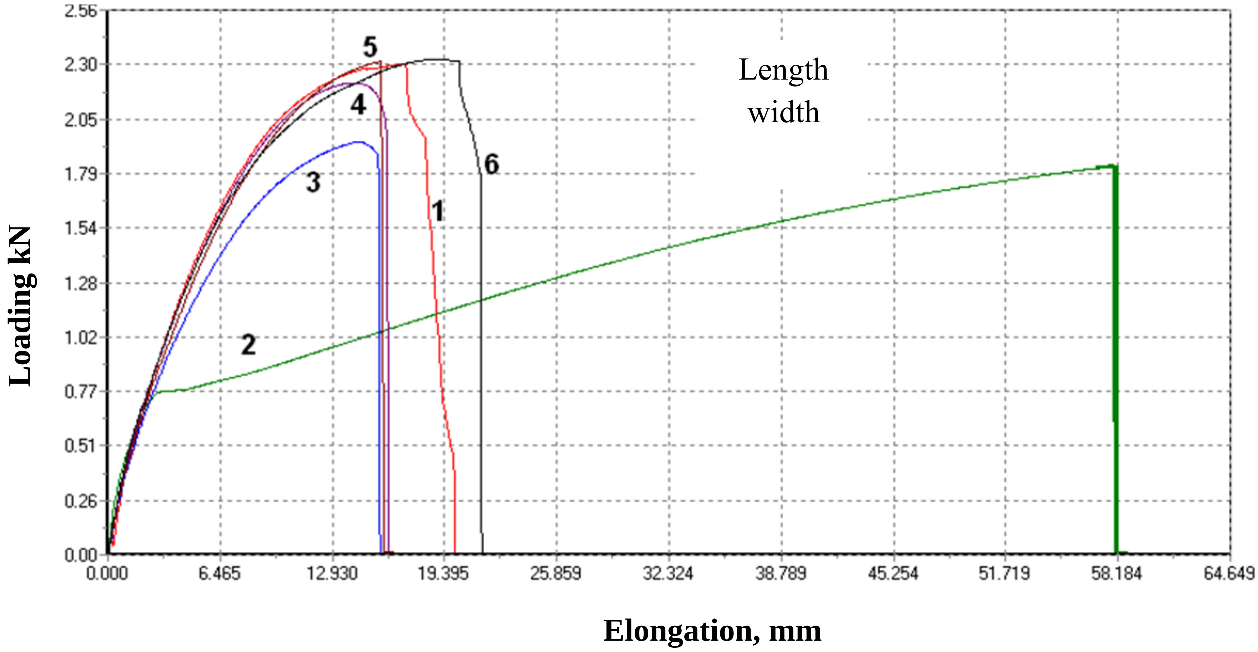


Fig 5. Diagram “loading – elongation” for rigid geogrid in longitudinal and transversal direction:
1 – initial sample;
2 – standard methodology 160°C – 120 min. without sand;
3 – temperature 157°C (sand) - 138°C (grid), is free state;
4 – temperature 158-132°C, grating is not fixed;
5 – temperature 174-140°C, grating is not fixed;
6 – temperature 195-134°C, grating is fixed.

Following the research it was determined that tensile strength results decreases non significantly (only on 7%) for polyester grid at temperature 160 ºC. (fig. 6). However, hereby elongation at break increases 2,44 times. Upon reinforcement calculations it is necessary to take into account that reduction coefficient of strength at elongation 2% and 5% is accordingly 1,58 and 2,11.

As it is seen at fig. 5 after heating elongation of samples increased significantly. It happened as a result of dissapearance of elastic deformation of fibers, which fabric is made of, previously stretched in the process of forming of geogrids, namely there was backward relaxation process upon heat influence, which resulted in shrinkage of bed and its elongation at loading increased.

Coefficient of grid characteristics change after thermal treatment is given in the table 4.

Estimated value of modulus of elasticity of polyester grids should be taken for material before thermal treatment 560,3 kN/m and 533,7 kN/m at elongation correspondently 2% and 5%. After thermal treatment estimated values of modulus of elasticity of polyester grids decrease more than two times and is 331,5 kN/m and 268,1 kN/m at correspondent elongation 2% and 5%.

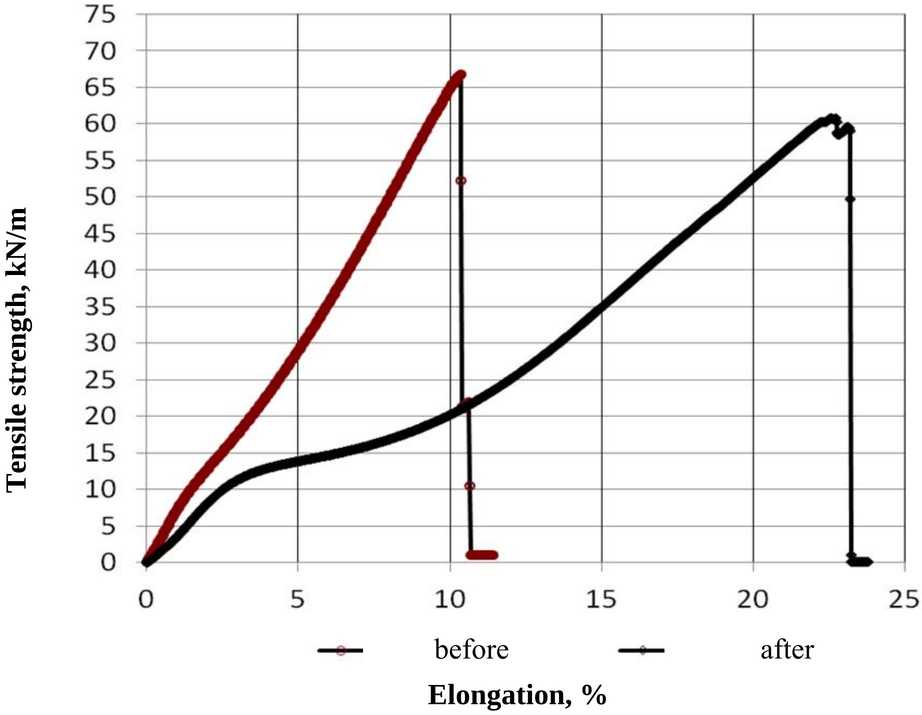


Fig. 6. Comparison of curve change “tensile strength – elongation” before and after thermal treatment

Research results could be considered upon application of polymeric geosynthetic materials for reinforcement of asphalt concrete layers of road and airfield pavements.

Table 4. Coefficient of characteristics change after thermal treatment

№	Strength change, kN/m			Relative elongation change, %		Modulus of elasticity	
	At elongation		At break	At break	At maximum loading	2%	5%
	$R_{2\%}$	$R_{5\%}$	R_{max}	ε_{max}	ε_{Rmax}	$E_{2\%}$	$E_{5\%}$
Relation of performance characteristics after thermal treatment to initial data							
Minimum	0,55	0,52	0,96	2,38	2,39	0,55	0,52
Maximum	0,65	0,45	0,92	2,48	2,39	0,65	0,45
Average	0,63	0,47	0,94	2,44	2,35	0,63	0,47
Standard	0,97	0,13	0,62	2,71	2,40	0,97	0,13
Coefficient of variation	1,54	0,28	0,66	1,11	1,02	1,54	0,28

Perspectives of further research works in this direction. If reasoned the sphere of application of different types of grids for reinforcement of asphalt concrete pavement it is necessary to consider in details raw materials, which grids are made of, resistance to high process able temperatures. It is necessary to add to standards’ requirements on thermal stability of grids, made of polymeric fibres.

Final decision on this issue is possible only on the base of data of direct testing of physical, mechanical and hydraulic performances of RGM. Upon comparative testing carrying out the estimation of performance properties is made and determined the most correspondent types of reinforcing materials, provided the best possible design solution. It is necessary to continue with research with other types of grids. It is interesting to establish factor of creep safety with the consideration of temperature influences on grids.

Comparative testing encourages piling up of theoretical and experimental data, which are necessary to increase the design quality and reliability of structures and stimulate development of technologies in road construction as well.

It is necessary to continue the research on application of other types of fibres and develop amendments to normative documentation concerning testing of geosynthetic materials as for thermal and heat resistance.

It is also necessary in calculations according to existing standards to take into account strength reduction factor and increase of relative elongation of geosynthetics after temperature effects upon asphalt concrete reinforcement.

Summary.
Materials for reinforcement of asphalt concrete pavements should be thermally stable and thermally resistant, preserving their properties after effect of temperature impacts in the range 130 – 175 ºC upon construction of layers of basement and pavement and 180 … 240 ºC upon repair of pavement with poured asphalt.
At the stage of design and estimation of reliability and durability of road pavement constructions of motorways it is necessary to consider changes of physical and mechanical properties of RGM, which occurs in the time of construction of asphalt concrete pavements.
Comparative characteristics of polymers for production of RGM shows that polypropylene fibres have low melting temperature 160 °C, that could bring to result of their disruption upon application of hot asphalt concrete mixtures, temperature of which during production should be from 140 to 165°C, subject to content of mixtures and type of used bitumen. More over, brittle temperature of polypropylene fibres is around 10 °C that could be the reason of their thermal stress cracking in winter time when there is combined action of strain subject to temperature gradient and loading. Polypropylene grids could be applied in the condition, when temperature of their heating is in the range of 100… 120°C, and the time of cooling up to 50°C is not over 30 minutes. To get positive results with application of polypropylene grids for reinforcement of asphalt concrete pavements their modification is necessary with the purpose to provide thermal resistance or it is necessary to change technology of construction asphalt concrete pavement. As a possible variant it could be protection of grid with thin layer of emulsion and mineral mixture (type Slurry Seal or Multimac) and over it the layer of hot asphalt concrete could be placed.
Carrying out input control on developed methodology upon grid choice will allow to avoid premature failure of reinforced asphalt concrete pavement.
Important characteristics to make choice of reinforced synthetic materials , namely change of linear dimensions (shrinkage) upon contact with asphalt concrete are not provided by producers and in state standards and construction standards correspondent norms should be developed.
Following the research results it was determined that, tensile strength decreases non significantly (only on 7%) for polyester grids at temperature 160 ºC. However, hereby it was discovered that elongation at break increased 2,44 times. For reinforcement estimation it is necessary to consider that reduction coefficient of strength at elongation 2% and 5% is correspondent to 1,58 and 2,11.
Estimated value of modulus of elasticity of polyester grids should be accepted for material before thermal treatment as 560,3 kN/m and 533,7 kN/m at elongation correspondently 2% and 5%. After thermal treatment estimated value of modulus of elasticity of polyester grids increases more than two times and equal to 331,5 kN/m and 268,1 kN/m at correspondent elongation 2% and 5%.
It is necessary to continue the research with application of other types of fibres and develop the additions to the normative documents on testing of geosynthetic materials on thermal stability and thermal resistance. It is also necessary in estimations on the base of existing norms [8] to consider strength reduction coefficient and increase of relative elongation of geosynthetics after temperature effect in reinforcement of asphalt concrete.

Reference list.

1. Koerner R.M. Designing with Geosynthetics, New Jersey, 5th, 2005, p. 796.
2. Over cracking control in asphalt concrete pavements [*Electronic resource*]. Retrieved from http://www.tensar.ru. (In Russian)
3. Tenax [*Electronic resource*]. Retrieved from http://www.tenax.net/ru/geosynthetics/ products/three-dimensional-geogrids-tenax-3d-grids_ru.htm. (In Russian)
4. Merzlikin A.E., Gladkov V.U., Gameliak I.P.. Reinforcement of asphalt concrete pavements in road pavements construction and repair. *Motorways:* Review information. CBSTI - Central Bureau of Science and Technical Information, Minavtodor of RSFSR., Moscow,1990, 5th Ed.,p. 45. (in Russian)
5. Gameliak I.P., Usychenko O.U., Dmitrenko L. A., Kolomiiets A. Y.. Research of thermal stability of rigid geogrids. Scientific notes. Lutsk, LNTU, Lutski Science and Technical University, Publ., Interuniversity collection, 2014 , pp.119-130. (in Ukranian)
6. Gameliak I.P., Bernadskii I.I., Dmitrenko L.A., Shatilo T. V.. Determination of thermal resistance an thermal stability of geogrids in reinforcement of asphalt concrete pavements. Motorways and road construction. Science and Technical collection book, Kiev, NTU, 2014, i.91, pp. 41-51. (in Russian)
7. GOST 29104.14-91 Technical fabric. Thermal stability determination method. (In Russian)
8. GBN B. 2.3-37641918-544:2014, Geosynthetic materials application in road constructions, Kiev, Ukravtodor Publ., 2014, p.144. (in Ukranian)