ISSN 2720-197X / eISSN 2956-3380

Agata KOWALEWSKA
Road and Bridge Research Institute
e-mail: ata.kowalewska@gmail.com; ORCID: 0000-0002-5819-8430

Krzysztof BLACHA
Air Force Institute of Technology
ORCID: 0000-0002-4599-4294

Mariusz WESOŁOWSKI
Military Institute of Armor and Automotive Technology
ORCID: 0000-0002-5545-8831

Sylwester KŁYSZ
Air Force Institute of Technology
ORCID: 0000-0002-4521-4972

DOI: 10.55676/asi.v4i2.97

ANALYSIS OF PHYSICO-CHEMICAL PROPERTIES OF GEOGRIDS USED FOR THE REINFORCEMENT OF NATURAL AIRFIELD PAVEMENTS

ANALIZA WŁAŚCIWOŚCI FIZYKO-MECHANICZNYCH GEOKRATY DO WZMACNIANIA NATURALNYCH NAWIERZCHNI LOTNISKOWYCH

Abstract

Geogrids applied to reinforce natural airfield pavements are polymer cellular geosynthetics with a spatial, permeable honeycomb structure. Geogrid is used to increase the safety of air operations by improving the load-bearing capacity of unreinforced airfield pavements. Laboratory tests of the applied plastic were one of the stages of verifying the efficiency of the suggested geogrid. Conducted tests showed that the used plastic is useful in manufacturing a geogrid. A geogrid neither deteriorates nor wears after applying a specific load thanks to its high durability properties. The load-bearing capacity of natural airfield pavements reinforced with a plastic geogrid improved by approximately 20%.

Keywords: physical and mechanical tests, safety of air operations, geogrid, natural airfield pavement, recycling

Streszczenie

Geokraty używane do wzmacniania naturalnych nawierzchni lotniskowych są to polimerowe geosyntetyki komórkowe o przestrzennej, przepuszczalnej strukturze plastra miodu. Geokrata stosowana jest do zwiększenia bezpieczeństwa wykonywania operacji lotniczych poprzez poprawę nośności nieutwardzonych nawierzchni lotniskowych. Jednym z etapów weryfikacji skuteczności proponowanej geokraty były badania laboratoryjne zastosowanego tworzywa sztucznego. Przeprowadzone testy wykazały, że wykorzystane tworzywo sztuczne jest przydatne do produkcji geokraty. Dzięki wysokim właściwościom wytrzymałościowym geokrata po przyłożeniu obciążenia nie ulega uszkodzeniu ani zniszczeniu. Nośność naturalnych nawierzchni lotniskowych wzmocnionych geokratą z tworzywa sztucznego uległa poprawie o około 20%.

Słowa kluczowe: badania fizyczne i mechaniczne, bezpieczeństwo operacji lotniczych, geokrata, naturalna nawierzchnia lotniskowa, recykling

Artykuł wpłynął do redakcji: 2.10.2023 / Zatwierdzono do publikacji: 30.12.2023

1. INTRODUCTION

Plastic geogrids are used to elevate the load-bearing capacity of unreinforced natural airfield pavements, which affects safety of air operations.

1.1. THE OVERVIEW OF THE EXISTING SOLUTIONS FOR REINFORCING UNREINFORCED PAVEMENTS

Geosynthetics are a common way of reinforcing unreinforced pavements. According to the standard[1] a geosynthetic is a product for which at least one component is made of a synthetic or natural polymer in the form of a sheet, tape or spatial form[2]. It is used in contact with the surface and/or other materi-als used in the geoengineering and construction industry. According to the American Society for Testing and Materials[3] geosynthetics are planar products manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering-related material as an integral part of a manmade project, structure, or system.

The article focuses on cellular geosynthetics. Geogrid is geosynthetics formed by a regular network of integrally connected elements with apertures greater than 6.35 mm (1/4 in.) to allow interlocking with surrounding soil, rock, earth and other surrounding materials to function primarily as reinforcement[4].

Primary geocells were manufactured from wax-coated craft paper, paperthin hexagonal glued aluminium and recycling materials. The roots of geocells date back to the late 1970s when the US Army Corps of Engineers Waterways Experiment Station (WES), in collaboration with Presto Products (currently Presto Geosystems, Appleton, WI, USA), developed Cellular Confinement Systems (CCS). CCS system aimed mainly at transferring high loads onto lower laying surfaces, which resulted in increasing the load-bearing capacity of the surface. Figure 1 shows the etching and testing efficiency of CCS manufactured from plastic and aluminium.

The load-bearing capacity of the surface is the possibility of the surface to transfer loads by the movement of vehicles or construction objects[5]. In the case of the weak soils on the surface (wet, unstable, organic, sensitive), the ap-plied external load, for instance: the aircraft strut wheel, will result in the deformation of the surface. Circular movement on weak, unreinforced natural airfield pavements results in the formation of ruts. A vertical force exerted by the wheel force leads to the displacement of the ground.

1 PN-EN ISO 10318:2007 Geosyntetyki – Terminy i Definicje.
2 M. Zhao, L. Zhang, X. Zou, H. Zhao, Research progress in two-direction composite foundation formed by geocell reinforced mattress and gravel piles, "Chines Journal of Highway and Transport" 2009, Vol. 22, Issue 1, p. 1.
3 ASTM D 4439-00 Standard Terminology for Geosynthetics.
4 Ibidem.
5 grunt-test, www.grunt-test.pl [access: 15.06.2022].

 DOI: 10.55676/asi.v4i2.97

In national and foreign literature, many reports which describe laboratory experiments of applying cellular geonet in structural layers under load. Article[6] delineates a series of static and cyclic load tests of slabs on a surface reinforced with a geocell with different filler materials, i.e. poorly sorted Kansas River sand, quarry waste and asphalt pavement from recycling. Based on performed tests, it was found that the geocell filled with poorly sorted sand, used to strengthen the ground, reduced the deformation of the ground (displacement under the load) and thus increased the bearing capacity of the ground. Deflection (displacement) of 10 mm was formed for the substrate: unreinforced at a stress of about 248 kPa; reinforced with a single geocell at a stress of approximately 477 kPa; reinforced with many cells at a stress of about 720 kPa, as shown in Figure 3[7]. The application of a cellular geonet also affected the possibility of decreasing the required thickness of the foundation to achieve the same parameters as the road on weak ground.

In this article, the authors suggest the application of plastic geogrid to improve the load-bearing capacity of natural pavements.

Only a few companies worldwide offer reinforcement of grass airfield pavements with geocells. Work examples presented below prove that using geocells on turf airfields and other pavements proves effective in many respects.

Figure 4 describes the usage of geogrid to make the road in river areas. Geogrids made of HDPE (High- Density Polyethylene) were applied. The manufacturer lists the following advantages: high durability to bending, low weight, quick installation, and ease of removal with the possibility of using them again, thanks to which they are economical.

Novus HM offered its solution as a TERRA-GRID geogrid ®E-35 to produce a runway on an airfield with turf surface – Figure 5. The experience of Novus HM indicates that applying geogrids on natural airfield pavements proves to be effective. One of the examples can be the inadequate runway drainage. It made it possible to use the runway all year round.

PERFO (United Kingdom)[8] invented a ground reinforcement system in the form of geogrids applicable in reinforcing, e.g. turf airfield pavements. Problems that needed to be solved using PERFO geogrids occurred on wetlands with water puddles. This system is employed on the whole airfield's functional elements or only in problematic areas. Figure 6 displays the PERFO geogrid used to reinforce the aircraft parking area.

In Poland, a runway on a natural airfield pavement was made using geogrids, e.g. on Narew 2 landing field. The runway pavement is 1, 500 m long and has been reinforced with plastic geogrid (Terra Grid). The landing field in Narew is the longest in

6 J. Han, J.K. Thakur, R.L. Parsons, S.K. Pokharel, D. Leshchinsky, X. Yang, A Summary of Research on Geocell-Reinforced Base Courses, conference paper, Design and Practice of Geosynthetic-Reinforced Soil Structures 2013.

7 Ibidem.

8 PERFO, http://www.perfo.co.uk [access: 15.06.2022].

the world amongst runways built with this technology[9]. Figure 7 shows the phase of laying geogrids on a turf airfield pavement.

1.2. PLASTICS AS A COMPONENT OF A GEOGRID

Plastics are materials whose basic components are organic macromolecular substances called polymers and usually additional components that affect processing and usage properties of polymers[10]. The discussed geogrid was formed by injection moulding of polyethylene and polypropylene, which were obtained during recycling plastic waste[11].

Polyethylene (PE) is an ethylene polymer with a repeating structural unit of the main chain $[CH_2 - CH_2]$[12]. Depending on the conditions under which polymerization takes place, polyethylene is divided into low-pressure and high-pressure polyethylene.

Low-pressure polyethylene has a high density (HDPE – High Density Polyethylene), it is formed during the polymerization reaction in the liquid phase at a temperature of 50–70°C[13]. The density of low-pressure polyethylene is in the range of about 0,94–0.97 g/cm^3 [14].

High-pressure polyethylene has a low density (LDPE – Low Density Polyethylene) and is obtained from ethylene in the gas phase at a pressure of 180–250 MPa, at a temperature of 200–250°C[15]. The density of low-pressure polyethylene is in the range of about 0.90–0.94 g/cm^3 [16].

Polypropylene (PP) ($[CH_2CH(CH_3)]$) is obtained in low-pressure polymer polymerization, which takes place in a solution at a temperature of 50°C to 100°C Polypropylene is one of the lightest plastics; its density is in the range of 0.85–0.92 g/cm^3 [17].

2. MATERIALS AND METHODS

Physico-mechanical properties of geogrid were assessed based on bending, tensile and compression tests. Tests were done according to the requirements of the European standards, which will be referred to in the description of particular tests.

9 PRONAR, www.pronar.pl [access: 15.06.2022].
10 E. Osiecka, Materiały budowlane. Tworzywa sztuczne, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2005.
11 M. Wesołowski, P. Włodarski, P. Iwanowski, A. Kowalewska, Analysis and Assessment of the Usefulness of Recycled Plastic Materials for the Production of Airfield Geocell, "Materials" 2021, Vol. 14.
12 E. Osiecka, Materiały budowlane..., op. cit.
13 A.J. Peacock, Handbook of polyethylene. Structures, Properties and Applications, CRC Press 2000.
14 Ibidem.
15 PN-EN ISO 10318:2007 Geosyntetyki – Terminy i Definicje.
16 A.J. Peacock, Handbook of polyethylene. Structures, Properties and Applications, CRC Press 2000.
17 Politechnika Wrocławska, www.tworzywa.pwr.wroc.pl [access: 14.03.2023].

 DOI: 10.55676/asi.v4i2.97

2.1. BENDING TESTS OF PLASTICS, FROM WHICH A GEOGRID IS MADE OF

According to[18], flexural strength is a conventional stress corresponding to the highest load force obtained during the bending test. After exceeding these stresses, the material is demolished. The bending test is done until a conventional deflection arrow is reached, which is s_c = 1.5 h, where h is the sample thickness[19]. Static bending tests of plastic samples were conducted according to PN-EN ISO 178:2019-06 Tworzywa sztuczne. Designation for bending properties[20]. Diagram for bending test is illustrated in Figure 8.

During the bending test under F force, the upper surface of the sample is reduced, and the lower elongated, resulting in compressive stress in the upper part and tensile stress in the lower part[21].

Bending tests were carried out on eight rectangular injection moulded samples, with dimensions of 80 x 10 x 4 mm, on a static testing machine type MTS 370.10 with a maximum load of 50 kN, using a force gauge type 1500ASK – 125 N with a measuring range of ±125 N and a displacement range of the actuator piston ±85 mm and a deflection extensometer type 632 06H-33 OPT 005 with a range of ±12.5 mm. Figure 9 shows a view of the samples before testing, Figure 10 shows view of the samples mounted in the testing machine before testing, and Figure 11 shows the view of the sample after stopping the test.

2.2. TENSILE STRENGTH TEST OF PLASTICS, FROM WHICH THE GEOGRID IS MADE OF

Tensile test consists in uniaxial strain of the appropriately prepared samples and measuring the resulting forces[22]. Static tensile tests of samples were conducted according to PN-EN ISO PN-EN ISO 527-1:2020-01 Tworzywa sztuczne. Designation for mechanical properties by static tensile. Part 1: General principles[23].

Tensile tests were made on five injection moulded samples from plastic, with the total length, width of the measuring section and thickness of 170 x 10 x 4 mm (Figure 12).

A view of the sample installed on a testing machine before a test is shown in Figure 13, and a view of the sample after stopping the test is illustrated in Figure 14.

18 Instytut Maszyn i Urządzeń Energetycznych Politechnika Śląska, www.imiue.polsl.pl [access: 15.06.2022].
19 Politechnika Wrocławska, www.tworzywa.pwr.wroc.pl [access: 14.03.2023].
20 PN-EN ISO 178:2019-06 Tworzywa sztuczne. Oznaczanie właściwości przy zginaniu.
21 T. Broniewski, J. Kapko, W. Płaczek, J. Thomalla, Metody badań i ocena właściwości tworzyw sztucznych, Wydawnictwo Naukowo-Techniczne, Warszawa 2000.
22 Ibidem.
23 PN-EN ISO 527-1:2020-01 Tworzywa sztuczne. Oznaczanie właściwości mechanicznych przy statycznym rozciąganiu. Część 1: Zasady ogólne.

2.3. COMPRESSION TEST OF PLASTIC GEOGRID

The compression test of geogrid was performed according to the standard PN-EN ISO 25619-2:2015-11 Geosyntetyki. Compression behaviour Part 2: Behaviour during short-term compression[24].

Five geogrids (an example geogrid before the test – Figure 15) with dimensions of 485 x 485 x 40 mm, which were injection moulded from plastic, were tested. Three geogrids were subjected to compression in the middle area; the other two were subjected to compression at the corners.

Figure 16 shows a geogrid installed in a testing machine before testing, and Figure 17 shows a geogrid after testing.

3. RESULTS

3.1. STATIC BENDING TESTS OF PLASTIC SAMPLES

Elastic modulus in bending Ef was determined from the slope of the secant, from the relationship of stresses $\sigma_{f2} - \sigma_{f1}$, which determines bending stress for the bending strain ε_{f2} = 0.0025 mm/mm and bending stress for the bending strain εf_1 = 0,0005 mm/mm, measured by deflection s_2 and s_1. Flexural modulus was calculated according to formula (1).

$$E_f = \frac{\sigma_{f2} - \sigma_{f1}}{\varepsilon_{f2} - \varepsilon_{f1}} \tag{1}$$

where:

σ_{f1} – is the flexural stress, measured at deflection s_1 [MPa],
σ_{f2} – is the flexural stress, measured at deflection s_2 [MPa].

The obtained results for designating the flexural modulus E_f for the population of 8 samples are illustrated in Table 3.1.

Table 3.1. Results for flexural modulus *Ef* for the population of 8 samples

Sample No.	E_f [1] [MPa]	$E_{fśr}$ [MPa]	$S_{(Ef)}$ [2] [MPa]	m_{Ef} [3] [MPa]	E_{fMNK} [4] [MPa]	$E_{fMNKśr}$ [MPa]	$S_{(EfMNK)}$ [5] [MPa]	m_{EfMNK} [6] [MPa]
1	946	947	14.8	$935 < m_{Ef} < 959$	940	944	14.1	$932 < m_{EfMNK} < 956$
2	935				937			
3	926				925			
4	938				938			
5	953				948			
6	973				973			
7	945				940			
8	959				952			

[1] modulus of elasticity in flexure, flexural modulus
[2] standard deviation of flexural modulus (secant)

[24] PN-EN ISO 25619-2:2015-11 Geosyntetyki. Zachowanie się podczas ściskania. Część 2: Zachowanie się podczas krótkotrwałego ściskania.

 DOI: 10.55676/asi.v4i2.97

[3] 95% two-sided confidence interval of the average values
[4] flexural modulus determined from the inclination of regression line determined with the least squares method
[5] standard deviation of flexural modulus (regression)
[6] 95% two-sided confidence interval of the average values

Source: own study.

The tested samples did not break during the test before reaching the conventional deflection arrow S_c (conventional deflection). In this case, a value that characterizes a given material in terms of its ability to transfer bending loads is the stress at a specific deflection arrow σ_{fc}, which is presented in Table 3.2.

Table 3.2. Results of bending stress under conventional deflection σ_{fC} for a population of 8 samples

Sample No.	σ_{fC} [1] [MPa]	$\sigma_{fC\acute{s}r}$ [MPa]	$S_{(\sigma fC)}$ [2] [MPa]	$m_{\sigma fC}$ [3] [MPa]	S_C [4] [mm]	ε_{fC} [5] [%]
1	17.6	17.5	0.14	$17.4 < m_{\sigma fC} < 17.6$	5.938	3.44
2	17.6				5.925	3.43
3	17.5				5.952	3.46
4	17.3				5.958	3.46
5	17.4				5.918	3.42
6	17.7				5.928	3.43
7	17.4				5.924	3.42
8	17.6				5.934	3.44

[1] flexural stress at the conventional deflection S_C
[2] standard deviation of bending stress by the conventional deflection s_C
[3] 95% two-sided confidence interval of the average values
[4] conventional deflection
[5] bending deformation for conventional deflection S_C

Source: own study.

The tested samples did not break during the test before reaching the conventional deflection arrow S_c (conventional deflection). In this case, the value that characterizes a given material in terms of its ability to transfer bending loads is the stress at a specific deflection arrow σ_{fc}. It is the highest normal stress (bending) occurring in the sample in the moment of strain S_c.

3.1. STATIC BENDING TESTS OF PLASTIC SAMPLES

Flexural modulus Et was calculated according to formula (2). The obtained results for Et are presented in Table 3.3.

$$E_t = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1} \quad (2)$$

where:

σ_1 – stress measured at strain value ε_1 = 0.0005 (0.05%) [MPa],
σ_2 – stress measured at strain value ε_2 = 0.0025 (0.25%) [MPa].

Table 3.3. Flexural modulus results E_t for the population of 5 samples

Sample No.	E_t[1] [MPa]	$E_{t,śr}$ [MPa]	$S_{(Et)}$[2] [MPa]	m_{Et}[3] [MPa]
1	900	913	26.5	889< m_{Et} < 939
2	890			
3	897			
4	955			
5	923			

[1] tensile modulus, modulus of elasticity under tension
[2] standard deviation of elastic modulus E_t
[3] 95% two-sided confidence interval of the average values

Source: own study.

Table 4 shows the results of determining Poisson's ratio v. Poisson's ratio is the negative ratio of the strain increase εn in one of the two directions perpendicular to the stretching direction, to the corresponding strain increase ε_l in the stretching direction, within the initial linear relationship of the longitudinal versus transverse strain curve – formula (3)[25].

$$\nu = -\frac{\varepsilon_n}{\varepsilon_l} \tag{3}$$

where:

ε_n – strain in the transverse direction [%],
ε_l – strain in the longitudinal direction [%].

Table 3.4. Results of the Poisson's ratio ν for the population of 5 samples

Sample No.	ν[1] [-]	$\nu_{śr}$ [-]	$S_{(\nu)}$[2] [-]	m_ν[3] [-]
1	0.49	0.494	0.0	0.48 < m_ν < 0.50
2	0.49			
3	0.49			
4	0.50			
5	0.50			

[1] Poisson's ratio
[2] standard deviation of the Poisson's v ratio
[3] 95% two-sided confidence interval of the average values

Source: own study.

The maximum tensile stress σ_m (tensile strength) is stress by the first maximum observed during the tensile test[26]. Tensile strength was calculated according to the formula (4), but the obtained results are illustrated in Table 3.5.

$$\sigma_m = \frac{F_M}{A} \tag{4}$$

25 A. Kowalewska, Wpływ zastosowania geokrat w podłożu gruntowym na nośność naturalnych nawierzchni lotniskowych w aspekcie bezpieczeństwa wykonywania operacji lotniczych, rozprawa doktorska, Warszawa 2022.

26 PN-EN ISO 527-1:2020-01 Tworzywa sztuczne. Oznaczanie właściwości mechanicznych przy statycznym rozciąganiu. Część 1: Zasady ogólne.

 DOI: 10.55676/asi.v4i2.97

where:

F_M – maximum tensile force [N],
A – surface of the initial cross-section [mm²].

Table 3.5. Results of the maximum stress σ_m for the population of 5 samples

Sample No.	σ_m [1] [MPa]	$\sigma_{m,śr}$ [MPa]	$S_{(\sigma m)}$ [2] [MPa]	$m_{\sigma m}$ [3] [MPa]
1	19.4	19.8	0.34	19.4 < $m_{\sigma m}$ < 20.2
2	20.0			
3	19.4			
4	20.1			
5	19.9			

[1] stress at the first local maximum observed during a tensile test
[2] standard deviation of strength σ_m
[3] 95% two-sided confidence interval of the average values

Source: own study.

Nominal strain $\varepsilon_{tm,ve}$ in the longitudinal direction at a maximum stress σ_m was shown in Table 3.6.

Table 3.6. Results at a maximum stress $\varepsilon_{tm,ve}$ for the population of 5 samples

Sample No.	$\varepsilon_{tm,ve}$ [1] [%]	$\varepsilon_{tm,ve,śr}$ [%]	$S_{(\varepsilon tm,ve)}$ [2] [%]	$m_{\varepsilon tm,ve}$ [3] [%]
1	10.2	10.1	0.40	9.7 < $m_{\varepsilon tm,ve}$ < 10.5
2	9.5			
3	10.5			
4	9.8			
5	10.3			

1 nominal strain in the longitudinal direction at a maximum stress σ_m
[2] standard deviation of the nominal strain in the longitudinal direction at a maximum stress σ_m
[3] 95% two-sided confidence interval of the average values

Source: own study.

The results of determining stress $\sigma_{b'}$ are included in Table 3.7, where the value of the nominal strain $\varepsilon_{tb,ve'}$ was determined in the longitudinal direction at stress $\sigma_{b'}$, which was assessed, providing that the sample did not break.

Table 3.7. Results of stress when the test $\sigma_{b'}$ for the population of 5 samples was finished

Sample No.	$\sigma_{b'}$ [1] [MPa]	$\sigma_{b',śr}$ [MPa]	$S_{(\sigma b')}$ [2] [MPa]	$m_{\sigma b'}$ [3] [MPa]	$\varepsilon_{tb,ve'}$ [4] [%]
1	14.1	14.2	0.29	13.9 < $m_{\sigma b'}$ < 14.5	160
2	14.4				
3	13.7				
4	14.4				
5	14.2				

[1] stress at rupture
[2] standard deviation of stress at the moment of finishing the test $\sigma_{b'}$
[3] 95% two-sided confidence interval of the average values
[4] nominal strain in the longitudinal direction at stress $\sigma_{b'}$; determined if the sample is not broken

Source: own study.

Stress σ versus strain ε_1 plot for one of the samples is shown in Figure 18, while the stress σ versus strain $\varepsilon_{t,ve}$ plot is shown in Figure 20.

The tested samples did not break. Rupture in the sample or elongation of the sample measured by a longitudinal extensometer of 4 mm was adopted as a criterion for finishing the test.

3.3. COMPRESSION TEST OF PLASTIC GEOGRIDS

Compressive strength during short-term compression σ_{mr}, which is the highest value of the compressive stress in the sample during the test, was determined according to formula (5), and the obtained results are illustrated in Table 3.8.

$$\sigma_{mr} = 10^{-3} \cdot F \cdot \frac{N_u}{N_{próbki}} \quad (5)$$

where:

F – compressive force [N],
N_u – number of elements in the samples in 1 m^2,
$N_{próbki}$ – number of loaded elements in the sample.

Table 3.8. Results of determining the compressive strength σ_{mr}

Sample No.	σ_{mr} [kPa]	$\sigma_{mr,śr}$ [kPa]	$S(\sigma_{mr})$ [kPa]
1	4836	4811	27.9
2	4817		
3	4781		
1-1	4110	-	
1-2	3759		
1-3	4082		
1-4	4287		

Source: own study.

Compressive strain ε_{mr} (ε), which was determined based on the displacement of the movable compressive slab relative to the base slab, was measured according to formula (6). Results of determining strain ε_{mr} were exhibited in Table 3.9.

$$\varepsilon_{mr} = 100 \cdot \frac{X_m}{d_{ij}} \quad (6)$$

where:

X_m – displacement of the movable slab corresponding to the maximum force F [mm],
d_{ij} – initial sample thickness [mm].

 DOI: 10.55676/asi.v4i2.97

Table 3.9. Results of determining compressive strain ε_{mr}

Sample No.	ε_{mr} [%]	$\varepsilon_{mr,śr}$ [%]	$S(\varepsilon_{mr})$ [%]
1	20	20	0.6
2	21		
3	20		
1-1	19	-	
1-2	18		
1-3	18		
1-4	19		

Source: own study.

During the tests, the compressive strain $\varepsilon_{mr,ve}$ (ε_{ve}) was determined using a video extensometer, which was calculated according to formula (7). Determined values of the compressive strain $\varepsilon_{mr,ve}$ are illustrated in Table 3.10.

$$\varepsilon_{mr,ve} = 100 \cdot \frac{X_{m,ve}}{L_0} \tag{7}$$

where:

$X_{m,ve}$ – displacement between video extensometer markers corresponding to the maximum force F_{mr} [mm],

L_0 – video extensometer base [mm].

Table 3.10. Results of determining compressive strain $\varepsilon_{mr,ve}$

Sample No.	$\varepsilon_{mr,ve}$ [%]	$\varepsilon_{mr,ve,śr}$ [%]	$S(\varepsilon_{mr,ve})$ [%]
1	14	14	0.0
2	14		
3	14		
1-1	16	-	
1-2	16		
1-3	15		
1-4	16		

Source: own study.

Stress σ_{mr} versus strain ε_{mr} and $\varepsilon_{mr,ve}$ diagram for one of the samples was exhibited in Figure 20.

4. DISCUSSION

The material tests showed that the plastic material from which the proposed geogrid is made has a very high resistance to static bending, static stretching and compression.

Samples subjected to the flexural strength test did not break before reaching the conventional deflection arrow S_c (conventional deflection). Therefore, the value characterizing the tested material in terms of its ability to transfer bending loads is the stress at a specific deflection arrow σ_{fc} = 17.5 MPa. The flexural modulus for the given plastic was E_f = 940 MPa, while the maximum stress σ_{fM} is 20.5 MPa.

The samples did not break during the tensile strength test. The following parameters were determined during the test: elastic modulus at rupture E_t = 913 MPa, Poisson's ratio ν = 0.494 [-], maximum tensile stress σ_m = 19.76 MPa, strain at maximum stress σ_m, $\varepsilon_{tm,ve}$ = 10.1%.

A single geogrid was tested for compressive strength. During the test, the compressive strength during short-term compression of the geogrid was found to be σ_{mr} = 4811 kPa and the deformation during compression was ε_{mr} = 20%.

Using the injection method, the geogrid in question was made of polyethylene with the chemical name 1-butene, a polymer with ethene. Typical properties of this material are shown in Table 4.1. The manufacturer of the material in question declares that it is resistant to acids, alkalis and alcohols.

Typical properties	Nominal value	Unit	Research Methodology
Melt Flow Rate (MFR) 190°C/2.16 kg 190°C/5.0 kg	 4.0 11.0	 g/10 min g/10 min	 ISO 1133-1 ISO 1133-1
Density	0.955	g/cm³	ISO 1183-1
Flexural modulus	1200	MPa	ISO 527-1, -2
Stress at the yield point	27	MPa	ISO 527-1, -2
Elongation at the yield point	8	%	ISO 527-1, -2
FNCT (3.5 MPa, 2% Arkopal N100, 80°C)	4.5	godz.	ISO 16770
Charpy impact test 23°C, Typ 1, karb A –30°C, Typ 1, karb A	4.0 4.5	kJ/m² kJ/m²	ISO 179 ISO 179
Shore hardness (Shore D)	60	-	ISO 868
Ball hardness (H 132/30)	52	MPa	ISO 2039-1
Vicat softening point (B/50 N)	73	°C	ISO 306

On the whole, the discussed plastic is used to produce the suggested geogrid. A geogrid neither deteriorates nor wears after applying a specific load thanks to its high durability properties. The load-bearing capacity of natural airfield pavements reinforced with the assessed plastic geogrid improved by approximately 20%.

5. CONCLUSIONS

Plastic is applied to produce geogrid, which is used to increase the safety of air operations by improving the load-bearing capacity of unreinforced airfield pavements. The tests of the plastic confirmed high strength properties, and that the geogrid was not destroyed after applying the load.

The article presents the results relating to one type of geogrid, which are part of a wider scope of research provided for under the project "Reinforcement system for natural airfield pavements on military airports, code name KRATA", with registration number DOB-BIO11/04/01/2020, financed by the National Research and Development Center as part of the National Defense and Security Program in competition No. 11/2020 round 2.

 DOI: 10.55676/asi.v4i2.97

Further works will focus on carrying out tests on other geogrid types and on making experimental plots on which field tests will be carried out. The technology of installing the geogrid and the load-bearing capacity of natural airfield pavements before and after using the geogrid will be assessed. The obtained results will provide the basis for further works.

REFERENCES

ASTM D 4439-00 Standard Terminology for Geosynthetics

Baran M., Lisiecki J., Nowakowski D., Raport z badania rozciągania statycznego próbek z tworzywa sztucznego, ITWL, Warszawa 2020.

Baran M., Lisiecki J., Raport z badania ściskania krat lotniskowych z tworzywa sztucznego, ITWL, Warszawa 2020.

Broniewski T., Kapko J., Płaczek W., Thomalla J., Metody badań i ocena właściwości tworzyw sztucznych, Wydawnictwo Naukowo-Techniczne, Warszawa 2000.

Greenfix Soil Stabilisation & Erosion Control, Presto Geosystems, The history of Geocells, 2016.

Gruin I., Ryszkowska J., Markiewicz B., Materiały polimerowe, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 1996.

grunt-test, www.grunt-test.pl [access: 15.06.2022].

Han J., Thakur J.K., Parsons R.L., Pokharel S.K., Leshchinsky D., Yang X., A Summary of Research on Geocell-Reinforced Base Courses. Design and Practice of Geosynthetic-Reinfoced Soil Structures, 2013.

Instytut Maszyn i Urządzeń Energetycznych Politechnika Śląska, www.imiue.polsl.pl [access: 15.06.2022].

Kowalewska A., Wpływ zastosowania geokrat w podłożu gruntowym na nośność naturalnych nawierzchni lotniskowych w aspekcie bezpieczeństwa wykonywania operacji lotniczych, Warszawa 2022.

Lisiecki J., Baran M., Raport z badania zginania statycznego próbek z tworzywa sztucznego, ITWL, Warszawa 2020.

Novus HM, https://www.novus-hm.com [access: 15.06.2022].

Osiecka E., Materiały budowlane. Tworzywa sztuczne, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2005.

Peacock A.J., Handbook of polyethylene. Structures, Properties and Applications, CRC Press 2000.

PERFO, http://www.perfo.co.uk [access: 15.06.2022].

PN-EN ISO 10318:2007 Geosyntetyki – Terminy i Definicje.

PN-EN ISO 178:2019-06 Tworzywa sztuczne. Oznaczanie właściwości przy zginaniu.

PN-EN ISO 527-1:2020-01 Tworzywa sztuczne. Oznaczanie właściwości mechanicznych przy statycznym rozciąganiu. Część 1: Zasady ogólne.

PN-EN ISO 25619-2:2015-11 Geosyntetyki. Zachowanie się podczas ściskania. Część 2: Zachowanie się podczas krótkotrwałego ściskania.

Politechnika Wrocławska, www.tworzywa.pwr.wroc.pl [access: 14.03.2023].

Presto GeoSystem, https://www.prestogeo.com [access: 15.06.2022].

PRONAR, www.pronar.pl [access: 15.06.2022].

Przegląd Lotniczy, www.plar.pl [access: 15.06.2022].

Wesołowski M., Włodarski P., Iwanowski P., Kowalewska A., Analysis and Assessment of the Usefulness of Recycled Plastic Materials for the Production of Airfield Geocell. “Materials 2021, 14”, 2021.

Zhao M., Zhang L., Zou X., Zhao H., Research progress in two-direction composite foundation formed by geocell reinforced mattress and gravel piles, “Chines Journal of Highway and Transport”, 2009.

 DOI: 10.55676/asi.v4i2.97