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Experimental investigation regarding the mechanical properties of poriferous Geocells produced in Iran

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Abstract
The use of various reinforcing materials is widely used for the stabilization and stabilization of beds, infrastructure, and soil slopes. Geosynthetics are one material and offer the advantages of high durability, reasonable price, wide application, and fast execution. Depending on the application, Geosynthetics come in different types, including geotextiles, Geocells, Geomembranes, Geogrids, Geofoams, Geonets, and Geocomposites. Each of these types plays a role in various fields such as reinforcement, isolation, moisture barrier, erosion control, and drainage, and considering that in the field of increasing soil bearing capacity, Geocells are the best type. Geocell has a very good performance in terms of increasing the bearing capacity compared to flat reinforcements, due to its cellular structure and providing the necessary confinement for the soil inside the cells. The use of Geocells is welcomed by many researchers due to the three-dimensional nature of their lattices. A unique poriferous Geocell was developed using unique technology through research on a three-dimensional honeycomb-type Geocell for enhancing bearing capacity, reinforcing soil fields, and vegetation base layers. In this paper, the characteristics of the original poriferous network structure are evaluated and the results are presented. The newly developed poriferous Geocell, which has passed the property evaluation, is expected to be applied as a competitive method in related fields in the future due to its excellent friction properties and differentiated permeability properties.

Keywords: Geosynthetic reinforcement, geocell, permeability, poriferous, normal stress, shear displacement

1. Introduction

Geocells are Geosynthetics that have a three-dimensional honeycomb shape by gluing together multiple strips of a certain width to exert reinforcing effects such as improving load-bearing capacity through particle confinement. It goes back to the research and development of the engineers of the United States Army in 1975, which were used to build tactical roads in soft soil and lose ground. During the research, the engineers concluded that the use of the storage system of coarse-grained sand and gravel can have a more suitable performance and result than crushed stones in the construction of roads with soft soil [1]. At the same time, it also has the property of preventing rapid destruction by moisture, which will have a more suitable and durable performance over a longer period. In 1981, engineers experimented by improving the previous design and using new raw materials such as slotted aluminum sheets and other materials such as plastic pipes. Geocells, it has a long lifespan, and besides being light, it also has a significant resistance to pressure [2]. The first factory to produce this product in the civilian system was Presto, which uses high-density polyethylene materials (HDPE type, which is lightweight, relatively strong, and affordable) for applications such as maintaining and controlling slopes and supporting Bar was used in the United States and Canada in the early 80s. Geocells are used in a wide range of fields, such as improving the bearing capacity of soft soil, the construction method of reinforced soil, the base layer of vegetation, and the hydraulic environment, on the other hand, in Iran, Geocell products have been used. That the active application and technical research in domestic-related fields are not possible due to the high dependence of the technology on the patented of foreign products Active are not done [3]. High product price and low commercial feasibility. However, by examining overseas cases, it is judged that it can guarantee a sufficient market in Iran with independent technology and realizing the product unit price through domestic production. The development of cell manufacturing technology was necessary along with the development of methods [4-5].

And related efforts to revive the industry. In response to these development needs, porous and environmentally friendly Geocells by researching Geocell products with unique domestic technology that does not conflict with foreign patented technologies. In the study, the domestic and foreign technology trend and characteristics of the developed porous Geocell products were evaluated and the results were presented [6].

2. Introduction and application of Geocells

Geocell is one of the most widely used members of a family of civil composites made of polyethylene fabric in an integrated manner without specific welding points. Polymers used in Geocell construction must be intact, completely clean, free from contamination, and not damaged by heat [7]. Important properties of Geocells are biological resistance, chemical resistance, UV resistance, heat resistance, tensile strength, and high modulus of elasticity, deformation at breakage, explosion resistance, abrasion resistance, and permeability. Today, Geocells are used in various fields of civil engineering, including geotechnical engineering. During the application of Geocell, it is possible to limit the lateral movement of soil, rubble, and concrete layers (before compaction), increasing the bearing capacity of the limited soil crust and reducing landslide settlement, distributing the traffic load over a larger area. Transfer the surface to the strata, reducing the thickness of the layer. Geocells are most widely used for the stability of embankments and slopes to increase the shear strength of the soil. Soils reinforced with Geocells have higher adhesion than unreinforced soils, improving soil resistance and durability. In addition, this product increases the hardness of the desired soil [8].

3. Types of Geocells

Geocells can be classified according to the type of strip that makes up the spring, the structure of the strip (monolith and perforated), and how the strips are connected (the structure of the connection point) [9].

3.1 Geocell Classification by Strip Type

Geocell strips have special holes. In other words, manufacturers usually provide whole sizes for Geocell wall strips. The hole determines the potential for water flow and the type of soil interaction on both sides of the Geocell cell wall. Geocells are made from non-woven geotextile strips, usually made of polyester. The water permeability and permeability properties of geotextiles, along with preventing the passage of soil particles, are among the properties of this type of geocell, and they lack resistance to the sun's ultraviolet rays and are relatively expensive compared to other strips used in construction Geocell. Plastic Geocells contain Geomembrane strips made of high-density polyethylene [10]. In general, Geomembrane is impermeable to fluid, and when used in saturated soil, drainage is impossible, so the permeation pressure increases by applying a load to the soil, while the effective stress of the soil decreases, that is, the shear strength of the soil decreases. This means to make, therefore, when using this product in a saturated place, it is recommended to use the perforated tape classified as follows.

3.2 Geocell classification according to strip structure

Two types of Geocells can be considered in this category: without holes and with holes. In Geocells without holes, water cannot drain or pass through the strip. Therefore, the use of this type of Geocell in saturated and agricultural soils is not suitable and perforated Geocells must be used to reinforce this type of soil [11]. Also, in this type of Geocell, there is no interaction between the soils on either side of the strip. In both cases mentioned above, the type of perforation of the tape is very important. Note that holes in the walls of perforated Geocell cells, in addition to allowing drainage from inside the Geocell layer, cause interactions and types of locking between particles inside the Geocell layer, reducing the required height of the Geocell. You should. Layers are compared to Geocells without holes [12].

3.3 Geocell Classification by Strip Connection Method

Another effective factor in evaluating Geocell type is how the strips are connected. Typically in factories, Geocell wall strips are made into a honeycomb shape using heating and special adhesives [13]. There are also technological advances in the production of Geocells from high-density polyethylene that contain holes for drainage at the connection point. In this way, the creation of the holes required for drainage does not reduce the tensile strength of the Geomembrane strip due to the reduced cross-section of the Geocell wall (creating a critical section).

4. Technology Trends

4.1. Geocell Public Principle

In general, when a load is applied to the soft foundation ground, the soil particles move from area 1 to area 3 and are destroyed as shown in Fig. 1(a), but as shown in Fig. This shows the effect of increasing the bearing capacity. In this way, the Geocell is applied in the form of a mattress with a continuous cell structure, showing a mechanism for distributing the load [14].

4.2. Geocell Product Trends

The Geocell was manufactured by joining through ultrasonic fusion, and the products with irregularities (embossing) were given to gradually improve the frictional properties of the strip and punched to give functions such as water permeability. Is accomplishing since then, products with differentiated welding methods have been developed, and products using non-woven strips have also appeared. In Iran, there are restrictions on the production of perforated products related to technology patents, so domestic production of the product is not performed. In addition, the initial investment cost of manufacturing facilities is too high, limiting the establishment of mass production systems, and thus localization is slow [15].

5. Development of Porous Geocells

5.1. Research background and purpose

As mentioned in the introduction, there is no active market formation in the application of the Geocell method in Iran. Compared to the superior functionality of the product, it had to be limited in domestic application due to the disadvantages of supply and demand of imported products, high unit price and exchange rate dependence of products, and high technological dependence. For the localization of Geocells, production was fundamentally impossible due to patent problems. In addition, it was difficult to promote R&D on unique products in a situation where there was a shortage of product experts. To overcome these difficult limitations, it was necessary to research and develop Geocell products differentiated by domestic technology and not infringing on overseas technology rights [16-17].

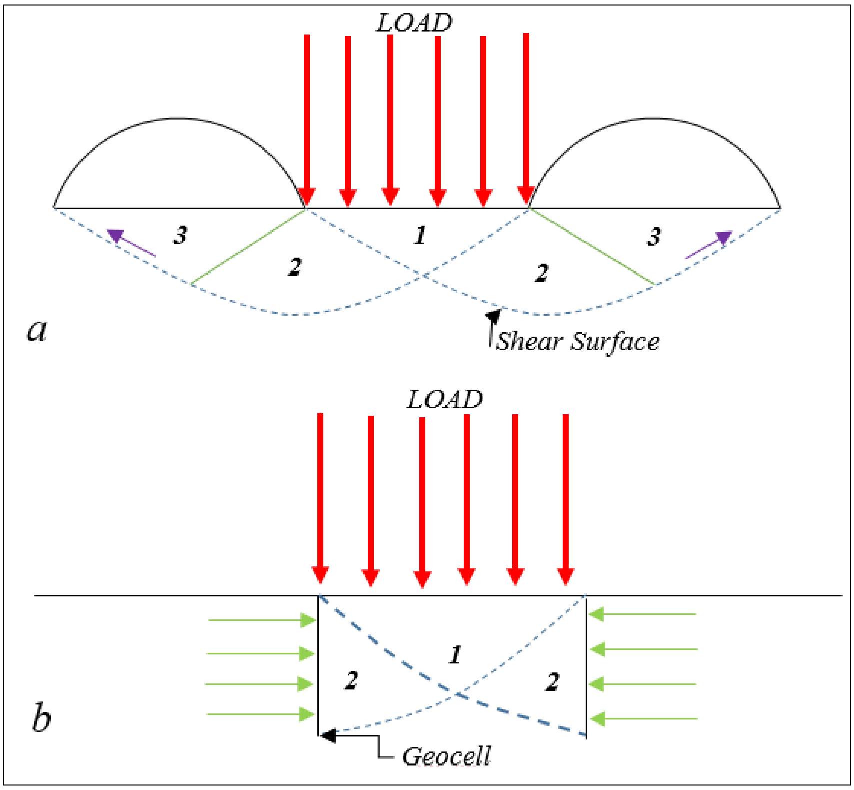

Fig 1: The Geocell load distribution mechanism

Table 1: Representative Geocell products and basic characteristics

Geocell products	Cell size mm	Texture	Note
DuPont	224 x 259	HDPE	Ultrasonic Welding
	287 x 320		
	475 x 508	PE	Heat Fusion
Ariankhak	200		
	300		
Poosheshsanat	224 x 259	HDPE	Ultrasonic Welding
	475 x 508		
Omranpooshesh	224 x 259	HDPE	Ultrasonic Welding
	287 x 320		
	475 x 508		
Taminyaran	264 x 218	Nonwoven	Stitching
	300 x 265		
	414 x 363		
Armature	One side 200mm regular hexagon	Nonwoven	Stitching

5.2. Development of porous Geocells
5.2.1 Development of porous strips
Polyethylene porosity is a research result derived to secure the frictional characteristics of existing Geocells and also to secure sufficient drainage characteristics (permeability). Strips manufactured through release extrusion can be expected to have an uneven effect and improved friction properties through voids, and it is expected that a strip with sufficient voids will be able to secure the flow of running water through the cell walls [18]. The network structure obtained through release extrusion as shown in Figure 3 was optimized to have sufficient mechanical properties, such as the size of the opening and the thickness of the rib.

5.2.2 Adhesion of porous strips
The most popular ultrasonic welding technique was applied for the bonding method of the strip. An ultrasonic welding machine suitable for porous strips was developed. Adhesive properties were reinforced by the front-facing adhesive method instead of the existing main-point adhesive method [20].

6. Features of porous Geocells
6.1. Geometric Features
The basic geometric properties of the developed porous Geocells, namely thickness, density, black carbon content, and unit weight were evaluated. The results and test criteria are shown in Table 2.

6.2. Mechanical properties
The main mechanical properties of the porous Geocell are strip tensile strength and peel resistance at the contact points. Each characteristic is evaluated according to ISO 13426-1. The tensile strength of the porous belt was 10.5 kN/m or more in the longitudinal direction and 8.0 kN/m or more in the width direction, and the adhesive strength was 5.5 kN/m or more. The images Geocell are shown in Figure 2.

Fig 2: Geocells made from poriferous strips

6.3 Mechanical properties

To evaluate the friction properties between the surface of the porous Geocell strip and the filling material, a large-scale direct shear testing machine was used.

Table 2: Geometric properties of porous Geocells

Item	Eigenvalues	Testing Method
Weight $^{g/m2}$	1305	ISO 13426-1:2019
Thickness ^{mm}	4.5	ISO/TC 221
Density $^{g/cm3}$	0.95	ASTM D1505 & ISO/AWI 9864
Carbon Black Content %	2.8	ASTM D 1603

Table 3: Basic mechanical properties of porous Geocells

Geocell products	Cell Height ^{mm}	Nominal Strip Tensile Strength $^{kgf/strip}$	Nominal Adhesive Peel Strength $^{kgf/seam}$
DuPont	42	42	25
	60	60	36
	90	90	54
	120	120	72

The friction angle was calculated using ASTM ^{D5321}. The large-scale direct shear testing machine has soil dimensions of 30 ^{cm} × 30 ^{cm}, and shear behavior is evaluated by applying residual loads of approximately 0.5, 1.0, and 1.5 $^{kgf/cm2}$ using a pneumatic load-bearing device. The internal friction angle of the granite weathered soil and the friction angle between the filler and the strip were obtained respectively, and the results are shown in Figures 3-4-5.

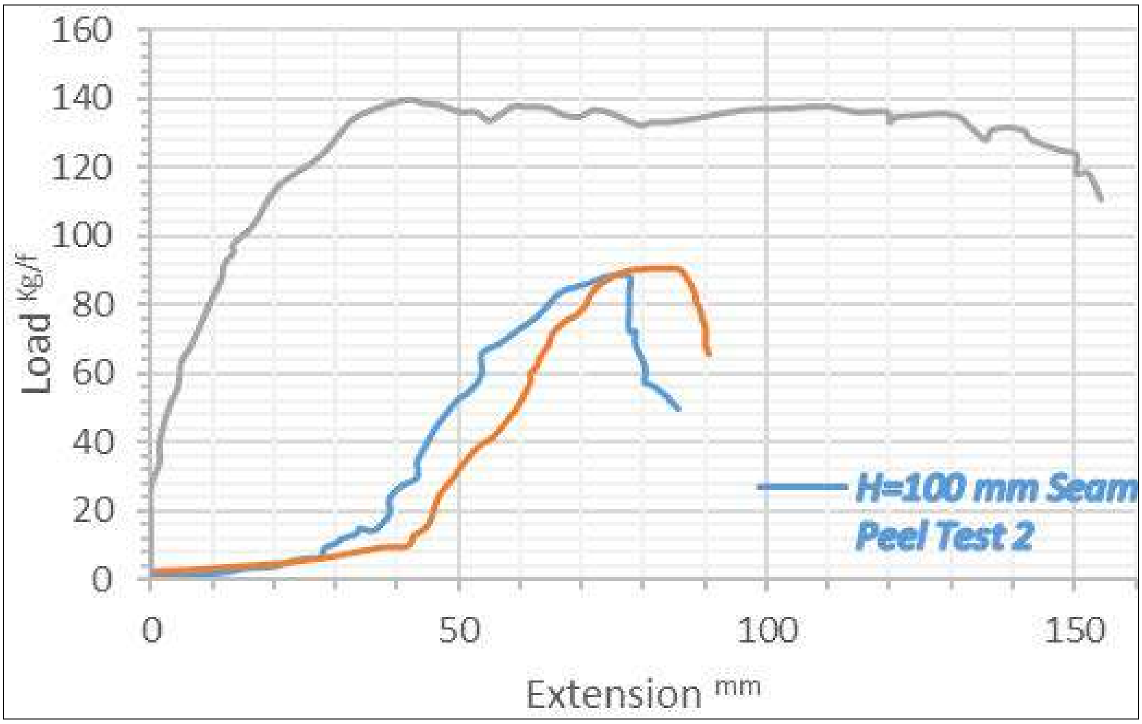

Fig 3: Representative curve of tensile test behavior of porous Geocell

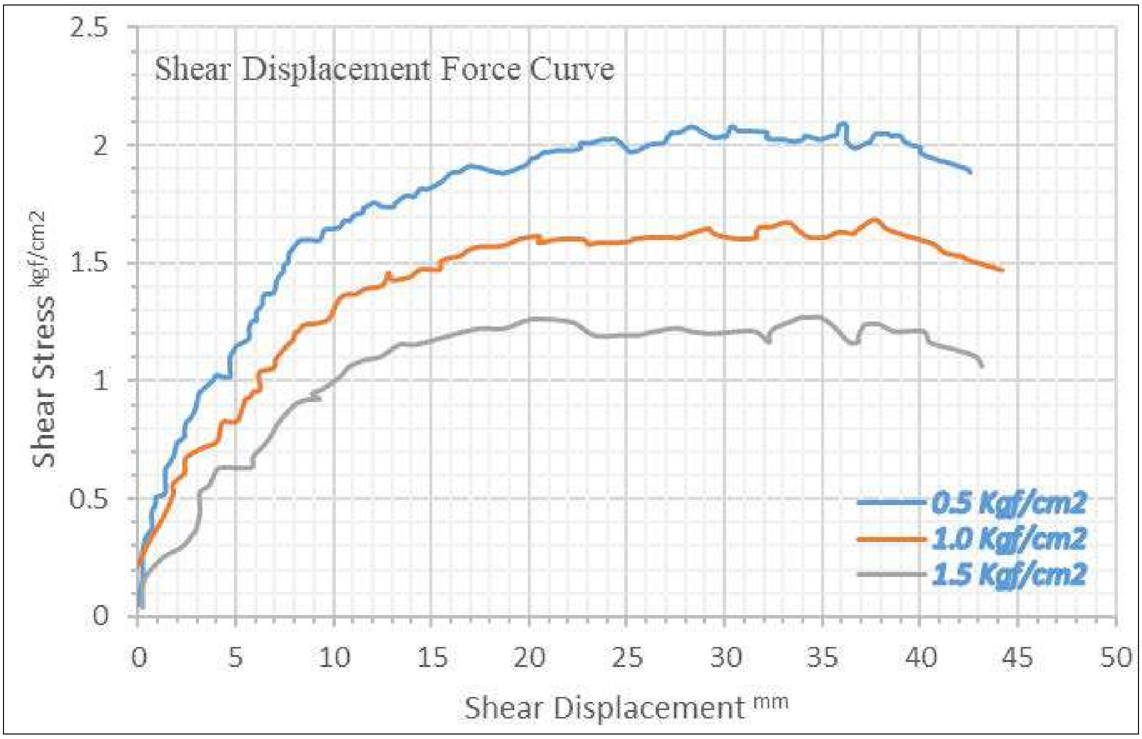

Fig.4: Shear Displacement Force Curve Geocell and filling material

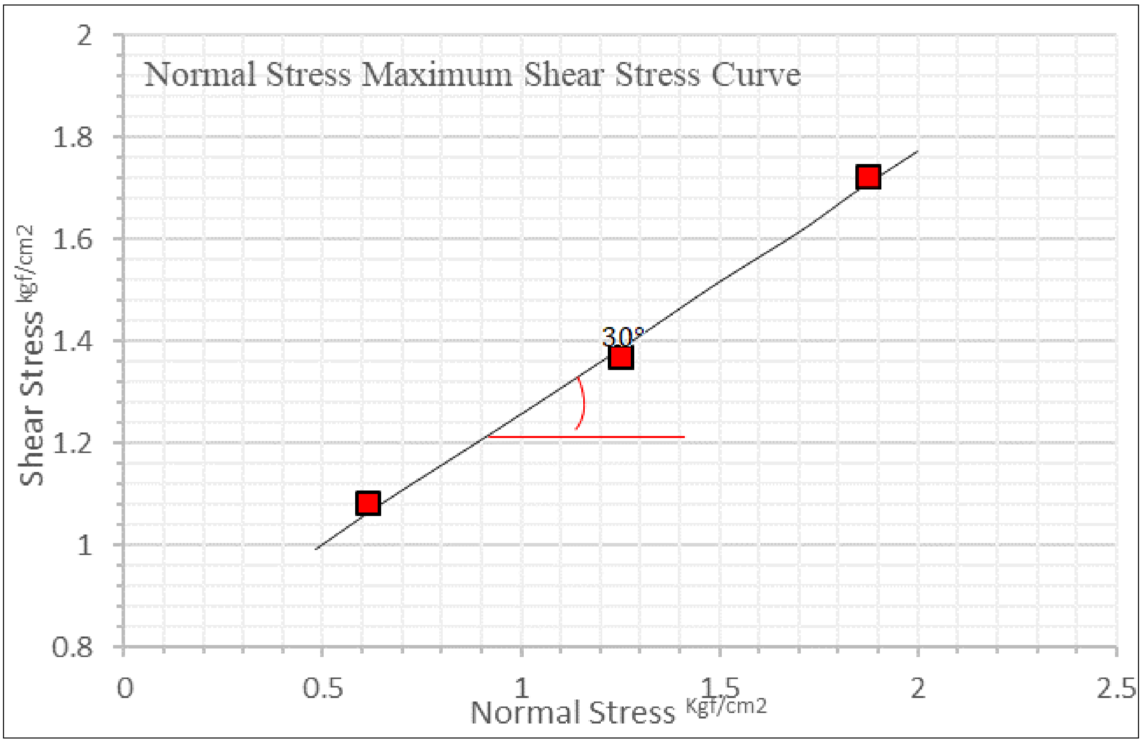

Fig 5: Normal Stress Force Curve Geocell and filling material

Table 4: Friction characteristics of porous Geocell strips [1]

Normal Stress kg/cm3	0.3	0.6	0.9
Maximum Shear Load kg/cm3	445.5	581.6	738.8
Shear Stress kg/cm3	0.5	0.7	0.87
Cohesion kg/cm3	0.33	Friction °	30°

The internal friction angle of the filler material is 35°. The friction angle between the weathered granite soil and the porous strip used in the experiment is 30°, which is almost equal to the internal friction angle of the filler.

6.4 Hydraulic properties

To evaluate the permeability characteristics of porous Geocells, it is most reasonable to evaluate cells filled with various fillers. The permeability coefficient of the cross-plane of the porous strip is evaluated according to ISO/TC 221& ISO 11058 and has a value of $8.9 \times 10^{-1 cm/c}$ or higher, which is the maximum value specified in the test method (loss head 50^{mm} condition).

1 Upper: Weathered soil Lower: Porous strip

6.5. Research on characteristic evaluation results

In the case of the existing porous Geocell, the value of the tensile properties is about 1.7 $^{kgf/cm}$, while in the case of the developed porous Geocell it shows a value of about 1.4 $^{kgf/cm}$, confirming that it has suitable stretch properties through an optimized release extrusion process. In addition, it can be confirmed that the turboelectric electrode with high-quality filler material shows that more than 80% can ensure sufficient friction efficiency due to the porous nature of the ribs and the three-dimensional effect of the mold release extrusion. This means a simplified manufacturing process compared to existing Geocell manufacturing processes, which require post-processing of embossing and perforation, reducing production costs. In addition, the excellent permeability of porosity is higher than that of porous fillers such as sand or aggregate, so it is judged that porous Geocells will have a particularly advantageous advantage when used as a drainage reinforcement layer. As mentioned above, through the evaluation of the short-term mechanical and hydraulic properties of the porous Geocells, it was confirmed that each had similar properties to the specific properties compared to existing products and was considered suitable. However, long-term UV stability and chemical resistance, etc., while stability can be inferred from the literature on polyethylene accumulated to date, additional research is required to derive product-specific data. The obtained results are in agreement with those of You, Jung *et al*. [19] within an acceptable range.

7. Conclusion

Geocell can provide lateral confinement of the soil within itself, thereby increasing the shear strength of the soil. This study developed a poriferous Geocell researched and developed for localization of Geocell products and enhancement of competitiveness through securing intellectual property rights with differentiated technology.

- A Geocell was manufactured through a porous strip optimized through R&D,
- The tensile strength of the porous Geocell was 12.35 $^{kN/m}$ or more (longitudinal direction), and the bonding strength was 7.65 $^{kN/m}$ or more,
- The friction angle between the porous Geocell cell wall and the weathered granite is it was $30°$, which was 79% of the internal friction angle of weathered granite.
- The permeability of the Geocell wall due to the porosity was $8.9 \times 10^{-1\ m/s}$.

The results show that by increasing the height of the geocell and increasing the number of springs per unit area, the carrying capacity of the soil increases. Also, increasing the width of the geocell up to about 5 times the width of the loading plate is effective in increasing the load capacity and after that, it has no significant effect.

The porous Geocell obtained as a result of the above study shows sufficient mechanical properties and is judged to have sufficient competitiveness in the field of Geocells with specialized excellent water permeability and improved friction properties. In addition, based on the developed products, it is expected that the related fields will be activated through the development of various methods and continuous research on technology.

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