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An experimental study on uniaxial compressive strength values of silicate based resin added sand samples with different types of fiber reinforcements

Farklı lif türleri ile güçlendirilmiş silikat bazlı reçine katkılı kum numunelerinin tek eksenli sıkışma dayanımı değerleri üzerine deneysel bir çalışma

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ABSTRACT

In this study, uniaxial compressive strength values of a sand type soil reinforced with polypropylene fiber and silicate-based resin additives with different amounts were investigated. Microgrid fiber (MGF) was tested as a new polypropylene fiber additive in the experiments to compare it with a conventional polypropylene fiber type geosynthetic product used in soil fill improvement applications. According to the findings obtained from the uniaxial compressive strength (unconfined compressive strength) tests, it was determined that the new MGF type fiber usually increased the strength values at higher rates in comparison with the conventional fiber product. As another outcome, it was found that target strength values can be supplied by using less resin amounts for the specimens with fiber additives. It was determined that proper strength improvements can be obtained more economically by the fiber additive use together with the resin, rather than the resin added mixtures without the fiber.

Keywords: Geofiber, geosynthetics, , microgrid fiber, resin added soils, strengths of sand type fills

ÖZET

Bu çalışmada, farklı oranlarda polipropilen lif ve silikat bazlı reçine katkı ile güçlendirilmiş kum türü bir zeminin tek eksenli sıkışma dayanımı değerleri incelenmiştir. Toprak dolgu uygulamalarında kullanımı yaygın olan bir polipropilen lif türü geosentetik ürünle kıyaslanması amacıyla deneylerde yeni bir polipropilen lif katkı olarak mikro hasır lif (MHL) test edilmiştir. Tek eksenli sıkışma dayanımı (serbest basınç mukavemeti) deneylerinden elde edilen bulgulara göre, MHL türü yeni lif ürünlerin geleneksel life kıyasla dayanım değerlerinde daha yüksek oranlarda artış sağladığı belirlenmiştir. Ayrıca, lif kullanımı ile kum türü zeminlerin istenilen dayanım değeri artışlarının daha az reçine kullanılarak sağlandığı görülmüştür. Lif katkının reçine ile birlikte kullanılması yolu ile lif içermeyen reçineli karışımlara kıyasla daha ekonomik olarak hedef dayanım değerlerine sahip olunabildiği belirlenmiştir.

Anahtar kelimeler: *Geofiber, geosentetikler, mikro hasır lif, reçine katkılı zeminler, kum türü dolgu dayanımları*

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INTRODUCTION

Geosynthetics are generally produced from polymeric materials and used in geotechnical engineering with different purposes like reinforcement, filling, isolation, drainage and etc. Geosynthetics can be used as an alternative to conventional materials, or can be used together with conventional materials in geotechnical engineering. Depending on the polymer material type, geosynthetics can be divided into two main groups as thermosets and thermoplastics. Thermosets are purchased before their polymerization as in the liquid form. One or more components of thermosets in the liquid form are mixed, chemically react with each other and solidify in a consequence of the polymerization. Thermoset geosynthetics are used in various applications of spraying membranes, grouting in anchorage holes, ground improvement injections and etc. (Guner and Ozturk, 2016; Holter, 2016; Sabri et al., 2021; Spagnoli, 2021; Komurlu, 2023a).

Although polymerization reactions of thermosets are typically completed within a day, a significant solidification generally happens in one hour. There are three stages of the thermoset polymerization. The first one is cream time; polymerization does not start and the mix of components is in the liquid phase in this stage. By the end of this time, the gel time and polymerization start. During the gel time, thermosets pass from the liquid phase to the solid phase. In the third stage called tack free time, material solidifies completely and the polymerization ends. Therefore, the maximum mechanical strength is reached at the end of the tack free time (Komurlu and Kesimal, 2015; Komurlu and Kesimal, 2017; Węgrzyk et al. 2023).

Depending on the application necessities, the thermoset products can be chosen considering their solidification times. For instance, quite short liquid phase times are preferred in spraying membrane applications. On the other hand, longer liquid phase times are preferred for ground injection works for supplying a proper penetration in the soil voids and/or cracks in rock masses. Also, relatively long cream and gel times are preferred in the resin added soil mixes used in filling applications to have enough time for a good homogenization property. Liquid phase times of different thermosets can vary within a big interval from several seconds to tens of minutes (Ajalloeian et al., 2013; Collico et al., 2023; Pratter et al., 2023).

Thermoset polymer resins can be injected into the soil in place or can be mixed with soils to prepare a filling material mix. Geosynthetics are preferred considering their mechanical properties and their high chemical resistances which make them advantageous in terms of their service lifetimes. Another important reason for using polymer materials is their high energy absorption capacities. Engineering polymers that provide good mechanical properties are preferred because of their strength values as well as their high energy absorption capacities (Komurlu et al., 2017; Kolay and Dhakal, 2020; Komurlu, 2021; Komurlu et al., 2014).

High energy absorption capacity geosynthetics supply an advantage of improvement under both static and dynamic load conditions by providing soil reinforcement. As some polymer resins can polymerize in contact with water, novel resin type geosynthetics can supply another important advantage in the watery regions against conventional materials (Luciani and Peila, 2019; Komurlu, 2020). Geosynthetics are also usable to improve the liquefaction resistance of soils (Latha and Lakkimsetti, 2022; Lakimsetti and Gali, 2023; Lakkimsetti and Latha, 2023). Due to their different advantages, the use of geosynthetics is becoming more widespread every day.

Fiber additive use is a reinforcement method for soil filling applications. Fiber additives which provide high adherence to the soil particles improve the reinforcement performance. For the supply of a good adherence property, the size and geometry properties of fibers are determinative (Patel and Singh, 2017; Divya et al., 2020; Patel and Singh, 2020; Tiwari et al., 2020) Also, fiber material has an important effect on the strength values of reinforced soils (Khajeh et al., 2020; Malicki et al., 2021; Zafar et al. 2023).

Microgrid fiber (MGF) is a new geosynthetic type with small mesh openings with sizes like several tens or hundreds of micrometers. Microgrid usage was previously investigated for soil improvement works as an alternative for the classical geogrids (Mittal and Shukla, 2019; Mittal and Shukla, 2020; Vieira and Pereira, 2022). The “microgrid” term is suggested to use for grid sizes below 2.5 mm according to the study authored by Leshchinsky et al. (2016). As a novelty of this study, microgrids were cut into pieces and used as a new fiber type for resin added soil mixes. In comparison with ordinary fiber products, it is estimated that the MGF reinforcement can provide higher adherence to soil particles due to its structural properties. MGF is the combination of thin plastic fiber ribs in groups of two or more different directions, which form mini grids. There are several structural properties that can vary the grid performances like rib dimensions, planar angles, junction characteristics, aperture size and shape. As similar with geogrids, MGFs can be biplanar, triplanar or quadroplanar. Lengths of MGF pieces can change in a typical interval of those of conventional geofibers. As a motivation of this study, a bettered adherence performance was estimated from MGF additives because combined fibers can work together in their use. In addition, grid type physical property was thought to make an additional friction coefficient for the soil particle contacts because proper adherence performances can be achieved by attaching grain edges to the grids. Grid type reinforcement inclusions can provide an interlocking mechanism with the grains (Gu et al., 2017; Hajitaheriha et al., 2021).

Good adherence property of the reinforcement provides a significant advantage not only in the strength values, but also in the crack propagation resistance, as well as the energy absorption capacity of the reinforced soil materials (Dhar and Hussain, 2019; Lv et al., 2021; Zhou et al. 2023). In this study, effect of a conventional polypropylene fiber (PPF) additive which is commonly used in geotechnical engineering and new MGF on the strength values of resin added sand type soil mixes were comparatively investigated with a series of experimental studies. It should be noted herein that the MGF additive is also made of the polypropylene type engineering polymer material. Details of the experimental study are given under the next section. Investigation of the new MGF type additive use can be noted herein as the main novelty of this study. In addition, use of different fiber types with resin additives is thought to be another remarkable point to make cost-effective solutions in soil improvement works.

MATERIALS VE METHODS

A sieve analysis was performed to classify the soil sample used in this study. The particle size distribution obtained from the sieve analysis is given in Table 1. According to the unified soil classification system (USCS), the soil sample with the Cu (coefficient of uniformity) value of 10 and the Cc (coefficient of curvature) value of 1.25 was classified as a well-graded sand (SW). As parameters for the soil classification system, 93.4% and 4.1% of particles are smaller than 4.76 mm (No. 4) and 0.075 mm (No. 200), respectively. The ratios by masses in the specimen contents with different amounts of resin and fiber additives are given in Table 2. The sandy soil having a natural moisture content of 19% was mixed with resin. The natural moisture content was determined by drying specimens at 105°C in the stove.

Table 1. Particle size distribution of the soil specimen

Tablo 1. Zemin numunesi tane boyu dağılımı

Sieve size	0.075 mm (No. 200)	0.150 mm (No. 100)	0.300 mm (No. 50)	0.850 mm (No. 20)	2.00 mm (No. 10)	4.76 mm (No.4)
% Passing	4.1	9.7	20.2	41.3	67.9	93.4

Table 2. Contents of specimens (M_{resin}: Mass of resin, M_{sand}: Mass of sand, M_{fiber}: Mass of fiber, M_{SR}: Mass of sand and resin, NF: No fiber)

Tablo 2. *Numune içerikleri (M_{resin}: Reçine kütlesi, M_{sand}: Kum kütlesi, M_{fiber}: Lif kütlesi, M_{SR}: Kum ve reçine kütlesi, NF: Lif yok)*

Specimen type	M_{resin}/M_{SR}	M_{sand}/M_{SR}	M_{fiber}/M_{SR}
8R-NF	0.08	0.92	0
14R-NF	0.14	0.86	0
20R-NF	0.20	0.80	0
8R-0.5PPF, 8R-0.5MGF	0.08	0.92	0.005
8R-1.0PPF, 8R-1.0MGF	0.08	0.92	0.010
8R-1.5PPF, 8R-1.5MGF	0.08	0.92	0.015
14R-0.5PPF, 14R-0.5MGF	0.14	0.86	0.005
14R-1.0PPF, 14R-1.0MGF	0.14	0.86	0.010
14R-1.5PPF, 14R-1.5MGF	0.14	0.86	0.015
20R-0.5PPF, 20R-0.5MGF	0.20	0.80	0.005
20R-1.0PPF, 20R-1.0MGF	0.20	0.80	0.010
20R-1.5PPF, 20R-1.5MGF	0.20	0.80	0.015

In Figure 1, MGF and PPF type polypropylene fibers are seen. Both MGF and PPF type fibers have 10 mm length. The MGF type fiber has square shape geometry with a width of 10 mm and the grid size of 1.2 mm. Contents of the mixes were sensitively weighed using an electronic scale (Figure 2). The resin was added in the specimen mixes as the last ingredient. Specimens were mixed by hand in a basin for 150 seconds. It should be noted herein that specimens were molded within the liquid phase time of the resin additive. 3 specimens were molded for the each specimen type. Specimens were filled into the molds in three layers and compacted with 15 hammer strokes after each layer (Figure 3). It was cared that details of molding and remolding processes were totally same for all the specimens used in this study. Diameter of the cylindrical split plastic molds is 50 mm and the ratio of length to diameter of the specimens is 2 in this study. Resin added specimens were cured for a day before the remolding process, and one week cured specimens were used in the UCS (uniaxial compressive strength) test. Specimens used in this study are seen in Figure 4. A sensitive electric motor press with the loading capacity of 50 kN was used to measure the load values (Figure 5). In the UCS test, the loading rate was chosen to be 0.5 mm/min.

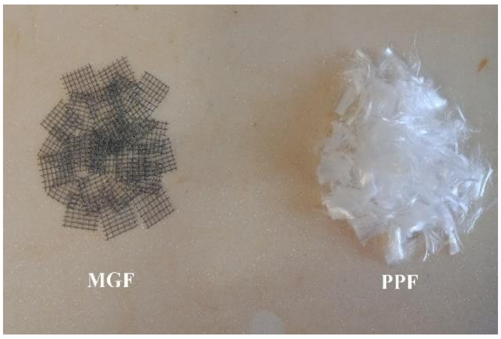

Figure 1. Fiber types used in this study
Şekil 1. *Çalışmada kullanılan lif türleri*

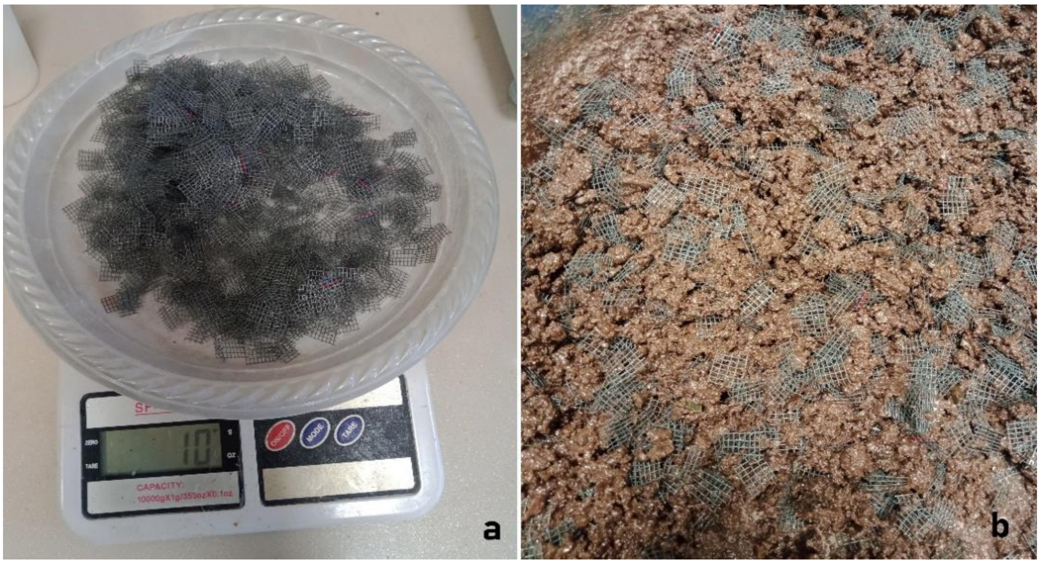

Figure 2. a) A photo from weighing processes, b) a view of MGF added soil mix
Şekil 2. *a) Tartım işlemlerinden bir görsel, b) MGF katkılı zemin görüntüsü*

Figure 3. a) Components of the resin, b) specimen mixing, c and d) specimen molding

Şekil 3. *a) Reçine birleşenleri, b) numune karıştırma, c ve d) numune kalıplama*

Figure 4. Specimens used in this study

Şekil 4. *Çalışmada kullanılan numuneler*

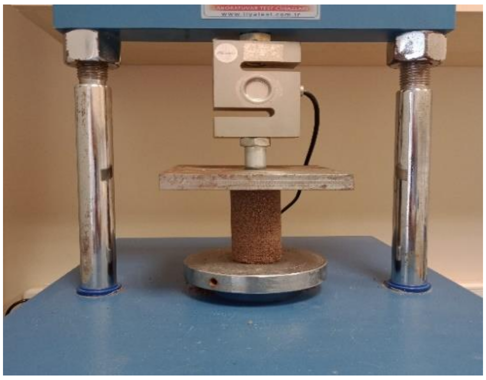

Figure 5. A photo from the uniaxial compressive strength test

Şekil 5. *Tek eksenli sıkışma dayanımı deneyinden bir görüntü*

RESULTS AND DISCUSSIONS

Uniaxial compressive strength (UCS) test results obtained from this study are given in Table 3. In addition, results of this study are graphically given in Figure 6 to comparatively show the strength values obtained from different specimen mixes. As it can be well estimated, strength values of specimens were determined to increase with an increase in the amount of resin additive. The fiber additive was also found to significantly improve the strength values of specimens. Instead of using only resin additive, it was evaluated that target strength values can be reached in a more economical way by using fiber reinforcement in resin added soils. Therefore, it was assessed to be advantageous to use fiber and resin additives together. To deal about the costs in the year of 2023, it can be noted that the price of the silicate based thermoset resin is 2.7 USD per a kilogram, and the price of polypropylene fiber products used in this study typically varies from 5.2 to 5.5 USD per a kilogram. The use of 20% resin additive means that 200 kg resin additive is used in a ton of the soil mix. In this case, 540 USD is spent for a ton of the soil mix. This price is too high for typical ground fill applications. In case 8% resin and 0.5% fiber are used together, the cost approximately decreases to 243 USD for a ton of the soil mix. In other words, the cost is reduced by more than half. The soil reinforcement costs can be made to be affordable by using fiber products in the resin added soils.

When the strength values and costs of the mixes are assessed together, it is recommended to use fiber reinforcement in resin added sands. The amount of fiber in the mixes is an important parameter that determines the strength value (Chou and Ngo, 2018; Zhao et al., 2020). Fiber additives must be used in the correct ratio in mixes. In the case of excessive use of fiber additives, strength values of soil mixes decrease (Gao et al., 2017; Mirzababaei et al., 2018). Threshold fiber content that begins to reduce strength values of resin-added samples may differ from those of resin-free and some other binder-free soils. Therefore, some resin added samples still had no decrease in strength values at the 1.5% fiber content rate.

Table 3. Uniaxial compressive strength (UCS) test results (SN: Specimen number, SD: Standard deviation)

Tablo 3. *Tek eksenli sıkışma dayanımı deney sonuçları (SN: Numune sayısı, SD: Standart sapma)*

Specimen type	UCS (MPa)	SN	SD (MPa)
8R-NF	1.05	3	0.08
14R-NF	1.73	3	0.07
20R-NF	2.61	3	0.15
8R-0.5PPF	2.67	3	0.19
8R-1.0PPF	3.08	3	0.26
8R-1.5PPF	3.90	3	0.21
14R-0.5PPF	9.23	3	0.58
14R-1.0PPF	11.74	3	0.52
14R-1.5PPF	12.15	3	0.63
20R-0.5PPF	14.64	3	0.75
20R-1.0PPF	17.51	3	0.84
20R-1.5PPF	12.20	3	0.71
8R-0.5MGF	2.81	3	0.23
8R-1.0MGF	3.97	3	0.29
8R-1.5MGF	4.69	3	0.26
14R-0.5MGF	10.64	3	0.90
14R-1.0MGF	13.80	3	0.85
14R-1.5MGF	10.99	3	0.78
20R-0.5MGF	13.22	3	0.60
20R-1.0MGF	21.74	3	0.97
20R-1.5MGF	17.58	3	1.03

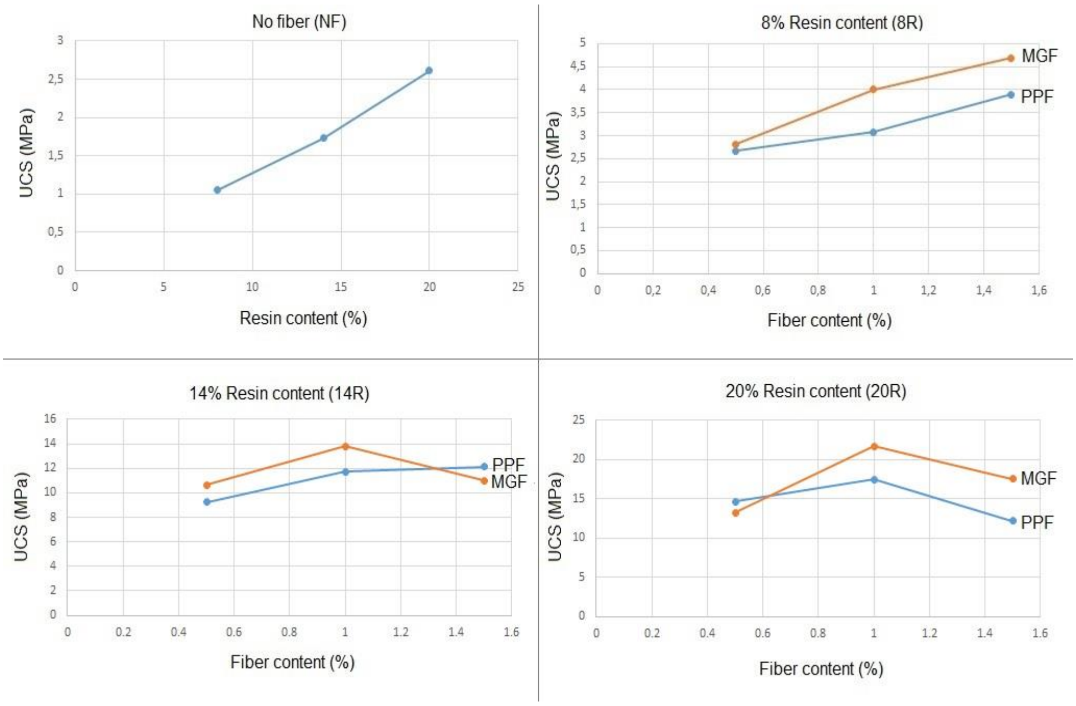

Figure 6. *Graphical shown of the UCS test results*

Şekil 6. *Tek eksenli sıkışma dayanımı deneyi sonuçlarının grafiksel gösterimi*

In this study, MGF additive was examined as a new fiber type and found usable to increase the strength values of soil mixes. According to the results of this study, it has been found that MGF type additive is usually more advantageous in terms of increasing in strength values, in comparison with the conventional PPF type fiber additive. This study is a preliminary one on the MGF usage to reinforce soils. In order to better understand the properties of the MGF additive, different parametric studies can be carried out within the scope of new investigations. For instance, different topics like grid size, fiber size and geometry, fiber material can be examined to better understand the effect of MGF additive use. Fiber size, geometry and material are important parameters varying the reinforcement performances (Shukla, 2017; Bos et al., 2019; Shafei et al., 2021). Likewise, the relationship between fiber size and soil particle size distribution is another important parameter in terms of strength values of fiber reinforced soil mixes (Pradhan et al., 2012; Anagnostopoulos et al., 2013; Yixian et al., 2016). It is possible to further improve the MGF additive efficiency within new studies on such issues. It is believed that there is a good potential for many new research topics for the use of MGF products as a new fiber type.

It has been observed from the MGF use that target strength values can be reached by using less fiber compared to the use of conventional fiber additives. In addition to the strength improvement purposes, fiber additives are also used for increasing the ductility and energy absorption capacity values of reinforced soils (Firoozi et al., 2017; Boz et al., 2018; Rathod and Reddy, 2021). It is also a new topic to investigate energy absorption capacity and ductility properties of MGF added soil mixes in the further studies. It is hoped that this study will be a beneficial reference for new researches on different fiber-reinforced soil mix designs.

It should be noted herein that the findings of this study are for the use of polypropylene type polymer fiber material. Both conventional and MGF type fibers used in this study are made of polypropylene type engineering polymer. Other geofiber materials can be investigated within further studies. In this regard, it should be noted that non-corrosive fiber materials must be preferred in soil mixes to prevent strength losses due to the ground water contact. Plastic geofiber materials like polypropylenes are advantageous as a result of their good chemical resistivity and non-corrosive property.

The soil reinforcement performance of MGF additives has been investigated in various research studies. In a previous study conducted by Komurlu (2023b), MGF-type fiber additives were utilized in cement-stabilized aggregate mixes. Similar to the findings of this study, it was observed that polypropylene MGF-type fibers provide greater increases in strength values compared to conventional polypropylene fiber (PPF) products. Komurlu (2023b) concluded that MGF-type novel additives offer improved adherence and reinforcement performance under both compression and indirect tension (splitting) conditions compared to conventional fiber additives.

Fiber additive is a strengthening method that can be preferred in ground filling applications.

In soil fill applications, issues such as curing times of resins, the order of additions to the mixture and the appropriate liquid phase time property of resin products should be considered in terms of obtaining a good homogeneity and proper reinforcement efficiency (Naeini et al., 2012; Masoumi et al., 2013; Vakili et al., 2023). High-strength soil fill materials can be created using different fiber and resin combinations. Following new materials and developments in material sciences can bring new solutions in geoengineering disciplines.

CONCLUSION

The following sentences can be noted to conclude this study: According to the results, the silicate based resin additive was assessed to notably increase the strength values of tested sand samples. On the other hand, it is suggested to use the resin additive with the fiber reinforcement in mixes to obtain better strength values while reducing the costs of the soil mixes. Different fiber types were comparatively tested and the microgrid fiber (MGF) was investigated as a new geofiber type within this study. Considering the outcomes of this study, MGF reinforcement was assessed to be able to supply better strength improvement of silicate resin added sand samples in comparison with a conventional fiber product. The MGF type fiber reinforcement was found to be usable and advantageous in soil filling works. There are numerous new research topics on MGF products with different designs and their use for different soil mixes. It is believed that MGF type new geofibers have a significant potential to become more popular in the near future of geotechnical engineering.

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