applied sciences

MDPI

Article

Bending Strength Evaluation of Three Dimensional Double Rachel Geosynthetic Cementitious Composite Mat (GCCM) under Environmental Conditions

Eunhee Ko [1], Daeyoung Lim [2], Seunghyun Kim [3,*], Jiho Youk [3,*] and Hanyong Jeon [3,*]

[1] Advanced Material & Process Development Team, Research & Development Division, KOTITI Testing & Research Institute, Seongnam 13202, Republic of Korea; ehko@kr.kotiti-global.com
[2] Human Convergence Technology Group, Korea Institute of Industrial Technology, Ansan 15588, Republic of Korea; zoro1967@kitech.re.kr
[3] Department of Chemical Engineering, Inha University, Incheon 22212, Republic of Korea
* Correspondence: shk@inha.ac.kr (S.K.); youk@inha.ac.kr (J.Y.); hyjeon@inha.ac.kr (H.J.); Tel.: +82-32-860-7493 (S.K.); +82-32-860-7498 (J.Y.); +82-32-872-1426 (H.J.)

Abstract: In this study, a reinforced geosynthetic cementitious composite mat (GCCM) with improved structural stability and reinforcement efficiency through yarn-in-lay technology was designed and manufactured. Additionally, a blowing agent was added to relax the cross-sectional reduction caused by the rapid curing and shrinkage for reduction of installation period. The impact resistance results showed a significant increase compared to the pre-reinforcement values. Through the analysis of blowing agent content, concrete filling ratio, and bending strength of the double raschel GCCM, optimal conditions were determined. Therefore, the double raschel GCCM showed improved flexural strength even after a short curing period of 10 days, along with excellent durability under environmental conditions.

Keywords: geosynthetic cementitious composite mat (GCCM); yarn-in-lay technology; blowing agent; impact resistance; bending strength; durability; environmental conditions

check for updates

Citation: Ko, E.; Lim, D.; Kim, S.; Youk, J.; Jeon, H. Bending Strength Evaluation of Three Dimensional Double Rachel Geosynthetic Cementitious Composite Mat (GCCM) under Environmental Conditions. *Appl. Sci.* **2023**, *13*, 11271. https://doi.org/10.3390/app132011271

Academic Editors: Sara Cattaneo and Manuela Alessandra Scamardo

Received: 7 July 2023
Revised: 9 October 2023
Accepted: 12 October 2023
Published: 13 October 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

When cracks form in concrete, they tend to propagate rapidly and eventually lead to failure. However, when reinforced with fibers, the progression of cracks is inhibited by the fibers embedded in the concrete, inducing a ductile failure effect. Fiber reinforced concretes (FRCs) have been used to improve the mechanical properties of concrete caused by its brittle nature [1–6]. This phenomenon known as flexible concrete behavior occurs when fiber reinforcement significantly increases the maximum stress and deformation of concrete even after the occurrence of cracks. Recently, FRCs using three dimensional fabrics have been developed to improve the reinforcement performance of concrete structures, these three dimensional fabrics have an excellent load-bearing capacity, ductility, thinness, lightweight characteristics, and exceptional resistance to corrosion [7–13]. However, despite these advantages, conventional FRCs has limitations due to the uniform dispersion of fibers caused by the two dimensional fabric layers. To overcome these limitations, it is necessary to develop a geosynthetic cementitious composite mat (GCCM), which is a reinforcing material to which a three dimensional structure is applied. The typical structure of a GCCM comprises an outer layer (; upper fabric) for concrete flow, an inner layer filled with concrete mixture, and an outer layer (; lower fabric) to prevent concrete loss, as shown in Figure 1. A major advantage of GCCMs is their rapid installation, enabling a rate up to 10 times faster, at 200 m^2/h, compared to using concrete alone. Due to its high stiffness and impermeability, GCCMs are used for applications such as slope protection and soil erosion control [14–19].

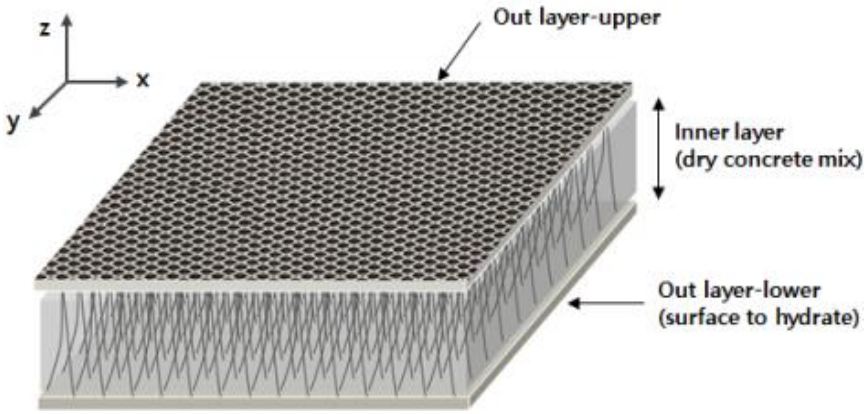


Figure 1. Schematic diagram of three dimensional GCCM structure.

Previous research on GCCMs has explored various aspects, including the tensile behavior of three dimensional fabrics with geometric patterns, patterns of GCCM upper and lower fabrics, three dimensional fabric structures modeling for seismic design, and mechanical behavior of needle punched structures in geotextiles [20–24]. Some studies have highlighted the challenges in maintaining consistent physical properties of needle punched GCCMs due to manufacturing methods and the adhesive strength between the fabric and cement. However, existing research has not adequately addressed the design of the 3D fiber structure of the upper and lower fabrics, or the seaming yarn of GCCMs. To maintain the advantageous constant physical properties of GCCMs, a holistic approach is needed, considering the integral fiber matrix structure design and exploring three-dimensional fiber matrix bonding between the fabric structure and the cement layer [25–28].

In this study, a three dimensional double raschel GCCM was manufactured using a raschel knitting machine, and basalt fibers were used as reinforcement yarn to control structural integrity and enhance the mechanical performance of the double raschel GCCM. The characteristics of the manufactured double raschel GCCM were analyzed based on concrete filling conditions. Furthermore, impact resistance was evaluated and bending strength was examined to verify the improvement of the concrete's ductile properties under environmental conditions.

2. Experimental Section

2.1. Double Raschel Structural Design

To manufacture a three dimensional fabric structure suitable for double raschel GCCM applications, several important factors were taken into account. These include designing an upper textile structure to facilitate smooth filling of dry cement powder, securing sufficient thickness to support the dry cement powder, and maintaining a lower textile density to prevent loss of the cement powder. Additionally, polyester DTY (Draw Textured Yarn) with a tensile strength of 830 kN/m^2 and a tensile strain of 14% was used to manufacture double raschel GCCM, and the manufactured double raschel GCCM must have appropriate mechanical properties and durability to withstand external environmental conditions. In this study, a three-dimensional double raschel structure was designed with these considerations. Yarn-in-lay technology was applied to regulate the elongation of the reinforcing yarn within the double raschel GCCM. To improve the overall durability against external environmental circumstances, basalt fiber was chosen as the reinforcing yarn for both the upper and lower layers (three dimensional fabric). The designed double raschel GCCM structure applied in this study is shown in Figure 2, and the yarn specifications for the double raschel GCCM are outlined in Table 1. The manufacturing process of the double raschel GCCM was carried out using a 12-gauge WONIL 104 double raschel machine (WONNIL Co. Ltd., Seoul, Republic of Korea).

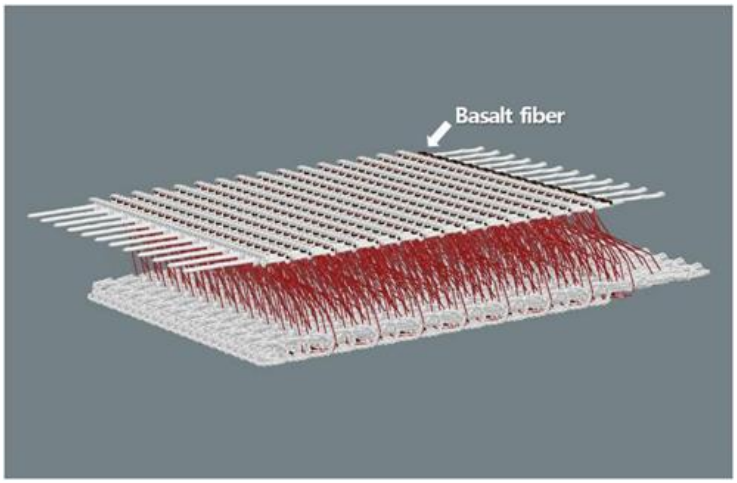


Figure 2. Schematic diagram of three dimensional double raschel GCCM.

Table 1. Yarn specifications of yarn for double raschel GCCM.

Yarn	Fineness
Basalt Yarn (warp/weft) (For covering)	600 denier/50 denier
Polyester DTY (warp/weft) (Draw Textured Yarn)	(2/300) denier/250 denier

2.2. Manufacturing of Double Raschel GCCM

The step-by-step manufacturing procedure of GCCM is represented in Figure 3. The GCCM produced in accordance with the process outlined in Figure 3 is employed following hydration at the construction site. During this hydration process, the cement's natural shrinkage results in a reduction of the concrete's cross-sectional area. Given that this phenomenon impacts the ultimate physical characteristics of GCCM, it becomes imperative to mitigate the extent of cross-sectional reduction.

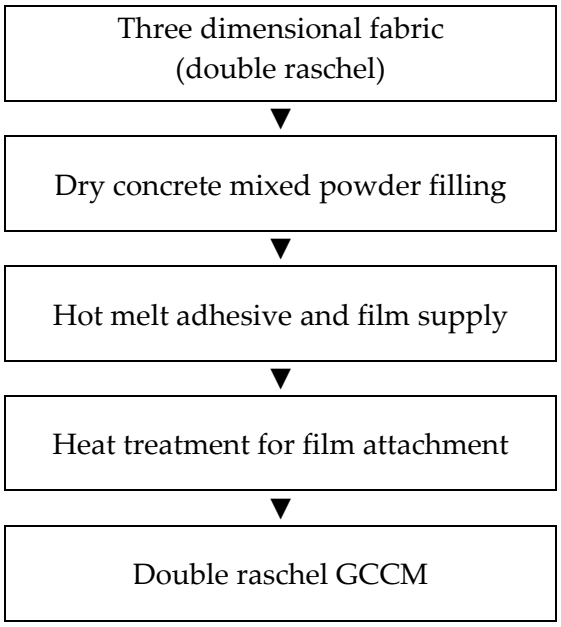


Figure 3. Manufacturing process of double raschel GCCM.

This study sought to achieve this minimization by assessing the concrete's volume change rates across various blowing agent concentrations and conducting image analysis before and after the addition of the blowing agent. The blowing agent contents of the double raschel GCCMs are 1, 3, 5, 7, 9, 11%, respectively. To investigate the characteristics based on the concrete filling ratio, an examination was conducted on how the physical properties change with respect to variations in concrete filling ratio, both before and after the application of foaming agent treatment using the same concrete filling quantity. The concrete filling amounts for the double raschel GCCMs are 530, 620, 710 g, respectively. In this study, a double raschel GCCM manufacturing process, as shown in Figure 3, was applied to produce a double raschel GCCM. Moreover, to improve workability—a distinctive feature of the double raschel GCCM—fast-setting cement was used to expedite the curing process, resulting in rapider and more efficient hardening. The Portland cement used in the formulation of the double raschel GCCM was a rapid-hardening cement mixture supplied by Golden Pow Co., Ltd. (Seoul, Republic of Korea). The typical compound compositions of this type are: 55% (C_3S), 19% (C_2S), 10% (C_3A), 7% (C_4AF), 2.8% MgO, 2.9% (SO_3), 1.0% ignition loss, and 1.0% free CaO (utilizing cement chemist notation).

2.3. Double Raschel GCCM Characteristics Evaluation

In order to analyze the impact resistance of double raschel GCCMs, a free fall test was conducted. For the free fall test, a weight of 5.98 kg was dropped from 0.25 m, 0.5 m, and 1.0 m to observe whether or not it was destroyed. In order to quantitatively analyze the impact energy delivered to each sample, the impact performance of the concrete before and after double raschel reinforcement was analyzed using an impact strength tester. The impact strength tester used was the IT504 from Tinius Olsen, and was measured according to the test standards of ASTM D256 (Izod). The evaluation of the double raschel GCCM's characteristics involved measuring its bending strength. Following the curing of the double raschel GCCM in accordance with ASTM C 1185, specimens, each with dimensions of 127 mm in width and 300 mm in length, were placed on supports spaced at 254 mm intervals. The bending test was conducted by applying pressure to the center of the specimen. The bending strengths of the double raschel GCCM were measured using Zwick's Zoo5 Universal Testing Machine (Zwick Roell GmbH & Co. KG, Ulm, Germany). For the concrete's physical properties, the standard curing period is typically 28 days. In this study, bending strength was evaluated at different curing periods (10 days, 30 days) using fast-setting cement. To assess the durability of double raschel GCCMs under environmental conditions, bending strength was evaluated in seawater and freezing and thawing conditions, as well as in acidic and alkaline solutions. After immersing the double raschel GCCM in seawater for 30 days, the bending strength was measured according to the ASTM C 1185 test standard. Considering the susceptibility of concrete to shrinkage cracks upon hardening, particularly under the cyclic conditions of freezing and thawing, a durability analysis was conducted under the assumption of seasonal changes from winter to spring. Freeze-thaw conditions were replicated for 30 days at alternating temperatures of 15 °C and room temperature, resembling the conditions of a domestic environment. The bending strength was assessed in accordance with the ASTM C 1185 test standard. The double raschel GCCM, cured for 10 days, was immersed in aqueous solutions of both pH 4 (acidic) and pH 12 (alkaline). Following treatment at 50 °C for 56 days, the bending strength was measured in accordance with the ASTM C 1185 test standard.

3. Results and Discussion

3.1. Characteristic Analysis of Double Raschel GCCM by Blowing Agent Content

The blowing agent was considered as a method to relax the cross-section reduction phenomenon caused by concrete shrinkage during the hydration of double raschel GCCMs. Curing was conducted over a 10-day period to assess the volume change with varying blowing agent content ranging from 1 to 11 wt%. While curing the concrete, a problem occurred in which the central portion became elevated due to the effects of the blowing

agent treatment. The volume change was quantified by measuring the amount of water needed to match the original volume of the specimens. Although the volume of the concrete increased as the blowing agent content rose, surface cracks were observed when the content reached 7 wt% or higher due to the formation of bubbles. The results of the volume change corresponding to different blowing agent contents are shown in Table 2, and the concrete's surface appearances are shown in Figure 4. Consequently, the optimal blowing agent content chosen was 5 wt%, providing the highest volume change without causing concrete surface cracking. This content was incorporated into the concrete mixture when manufacturing the double raschel GCCM.

Table 2. Volume change of double raschel GCCM with blowing agent content.

Blowing Agent Content (wt%)	**1**	**3**	**5**	**7**	**9**	**11**
Volume change (%)	6.25	9.38	11.25	15.63	18.13	18.75
Surface texture	Smooth			Cracked		

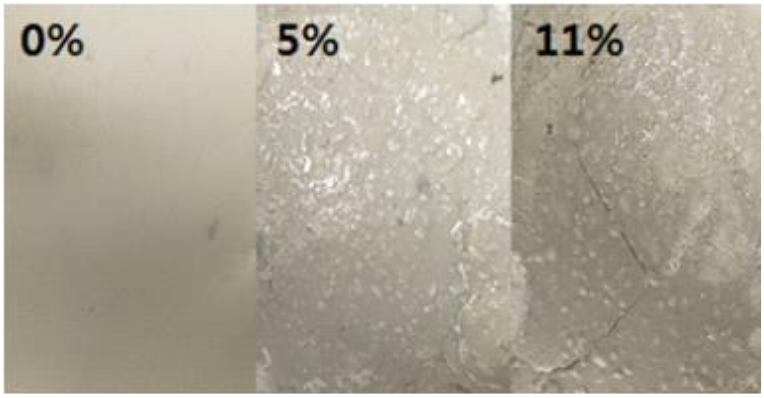


Figure 4. Photographs of Surface change of concrete with blowing agent content.

3.2. Analysis of Double Lassel GCCM Characteristics by Concrete Filling Factor

To analyze the characteristics of double raschel GCCMs in relation to concrete filling rates, three different concrete weights of 530 g, 620 g, and 710 g were used to create Samples-C1 to C6, with the blowing agent addition. Photographs of the concrete cross-sections, both with and without blowing agent addition, are shown in Figure 5. The 530 g filling represents the middle layer of the double raschel GCCM, 620 g fills up to the upper fabric, and 710 g overfills beyond the upper fabric. Samples-C1 to C3 were prepared without the blowing agent addition, while Samples C4 to C6 were cured for a duration of 10 days after 5 wt% of a blowing agent was added. Upon examining the cross-sectional image of Sample-C1, it became evident that despite filling the middle layer of the double raschel GCCM, a reduction in cross-section was observed due to curing shrinkage. Similarly, Sample-C2, which was filled up to the upper fabric layer, exhibited a void in the middle. Particularly, Sample-C3, involving overfilling beyond the upper fabric, showed more extensive curing. Cross-sectional images of both Sample-C1 to C3 and Sample-C4 to C6 were analyzed, and comparisons were made between sections treated with the blowing agent and those without treatment. It is seen that the phenomenon of cross-section reduction attributed to concrete shrinkage during hydration was relaxed through the use of the blowing agent addition at equivalent concrete content levels.

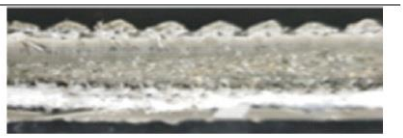
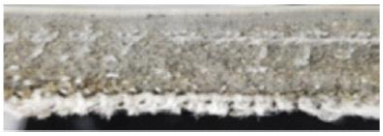
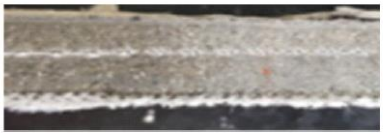
Concrete Filling Amount (gram)	Before Blowing Agent Addition	After Blowing Agent Addition
530	 Sample-C1	 Sample-C4
620	 Sample-C2	 Sample-C5
710	 Sample-C3	 Sample-C6

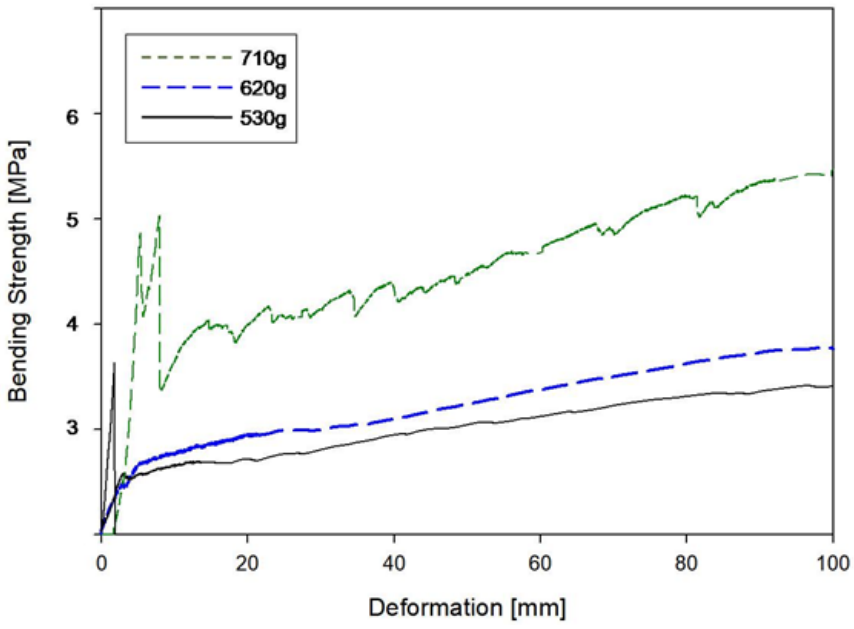
Figure 5. Photographs of cross-sections of double raschel GCCM with blowing agent addition.

Table 3 shows the thickness, filling factor, and bending strength measurements of GCCMs with and without blowing agent addition. For comparing Sample-C1 and Sample-C4, it is seen that the filling rate is nearly 100% when using a concrete filling amount of 530 g with blowing agent addition. However, upon contrasting Sample-C2 and Sample-C4, both characterized by similar filling rates, it is seen that the bending strength slightly decreased in the sample with blowing agent addition, in comparison to the sample without blowing agent addition. This phenomenon can likely be attributed to the formation of bubbles within the concrete due to the blowing agent addition.

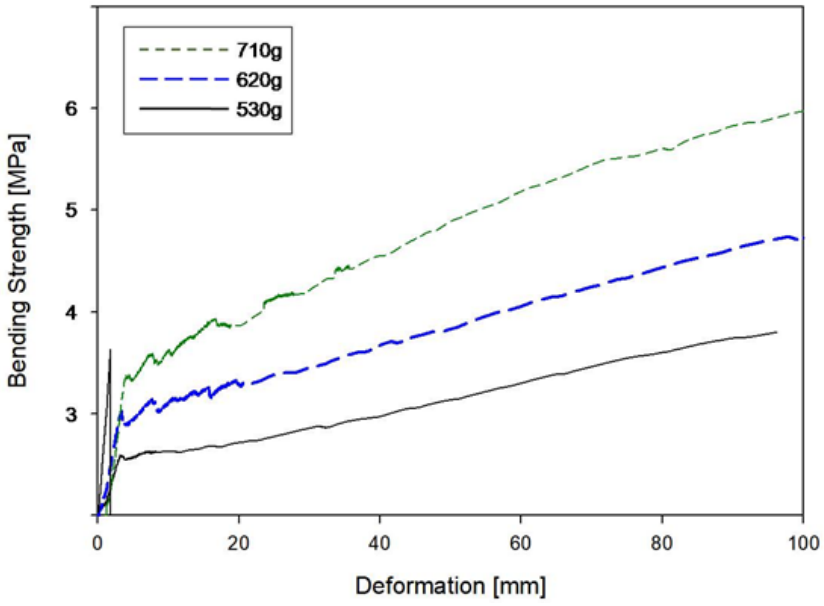
Table 3. Concrete filling content of double raschel GCCM with blowing agent addition.

Content	**Before Blowing Agent Addition**		
Name	**Sample-C1**	**Sample-C2**	**Sample-C3**
Concrete Filling Amount (gram)	530	620	710
Thickness (mm)	11.3	11.9	13.4
Filling Content (%)	92	98	105
Bending Strength (MPa)	2.97	3.22	5.12
Content	**After Blowing Agent Addition**		
Name	**Sample-C4**	**Sample-C5**	**Sample-C6**
Concrete Filling Amount (gram)	530	620	710
Thickness (mm)	11.3	13.2	14.2
Filling Content (%)	99	104	123
Bending Strength (MPa)	3.21	4.32	5.98

Figure 6a shows the relationship between bending strength and filling factor, while Figure 6b shows the bending strength with blowing agent addition under equivalent filling amounts. Irrespective of whether the blowing agent was used or not, there was a noticeable trend of increasing bending strength with a higher filling factor of the concrete. Particularly when the concrete filling rate surpassed 100%, the increase in bending strength exceeded 160%, as shown by Sample-C3. From this, it is seen that a concrete filling rate exceeding 100% is essential for the inherent physical properties of double raschel GCCMs to appear.



(**a**) Before



(**b**) After

Figure 6. Bending strength–deformation curves of double raschel GCCM with blowing agent addition.

Figure 7 shows the fracture surface images of double raschel GCCMs with and without blowing agent addition. The variation in fracture surface due to blowing agent addition was found to be insignificant. However, when reinforcing fibers are present on the fracture surface, the damaged concrete adheres to the specimen. On the other hand, when there is a cured concrete layered over the reinforcing fibers, it fractures during the bending strength test. This leads to the detachment of the concrete, similar to what occurs in unreinforced concrete. It can be thought that the concrete's curing process, containing concrete filling for the double raschel GCCM, as seen in samples such as Sample-C3 and Sample-C6, affects the area's weakness for brittle concrete fractures.

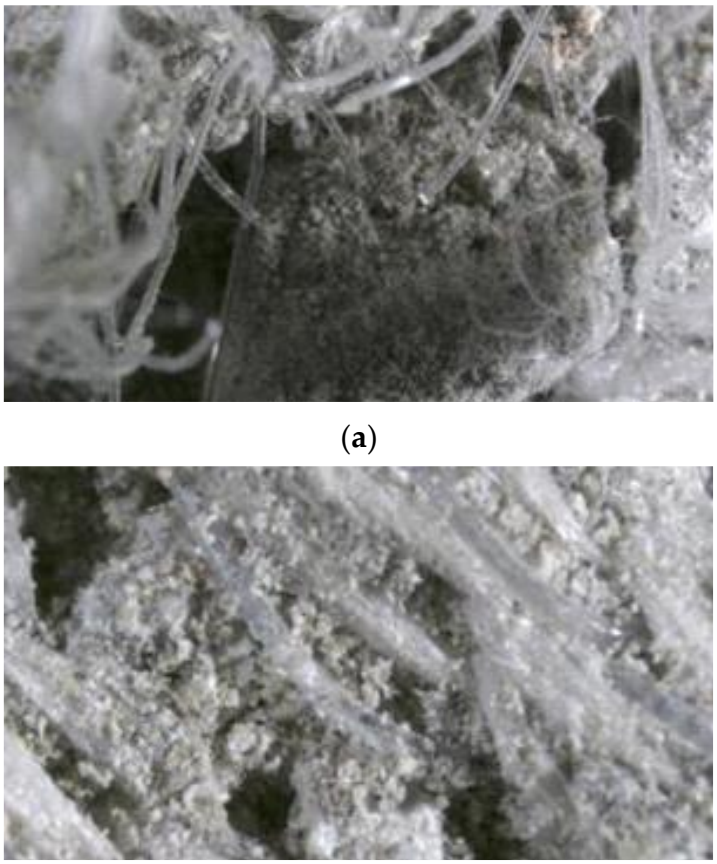


Figure 7. Fracture surface of double raschel GCCM with blowing agent addition. (**a**) For using reinforcing fiber; (**b**) For not using reinforcing fiber.

3.3. Impact Resistance Analysis of Double Raschel GCCM

To confirm the reinforcing effect on brittle fracture occurrence in general concrete, both general concrete and the double raschel GCCM were cured for 30 days. An impact resistance test was conducted through a free fall test on the general concrete and double raschel GCCM samples. The photographs resulting from the free fall test are shown in Figure 8. After conducting the free fall test, it was observed that when dropped from a height of 0.25 m, the normal concrete exhibited an immediate tendency to fail. However, in the case of the double raschel GCCM, deformation occurred on the rear side without resulting in destruction. The double raschel GCCM displayed backside deformations measuring 0.2 mm, 0.5 mm, and 1.2 mm at drop heights of 0.25 m, 0.5 m, and 1.0 m, respectively. Figure 9 shows the double raschel GCCM sample after the free fall test. General concrete showed a brittle fracture owing to the rapid propagation of cracks, contrasting with the double raschel GCCM which remained free from fractures at drop heights of 0.25 m and 0.5 m; however, a partial plastic fracture was observed at a drop height of 1.0 m. This indicates the reinforcing effect of the double raschel GCCM on the brittle fracture likelihood in concrete.

Furthermore, in order to perform a quantitative analysis of the impact energy applied to each sample, the impact performance of the concrete was evaluated both before and after the introduction of the double raschel GCCM. This evaluation was carried out using an impact strength tester, and the corresponding test results are shown in Table 4. The average bending strength value was obtained from five measurements for each individual experimental condition.

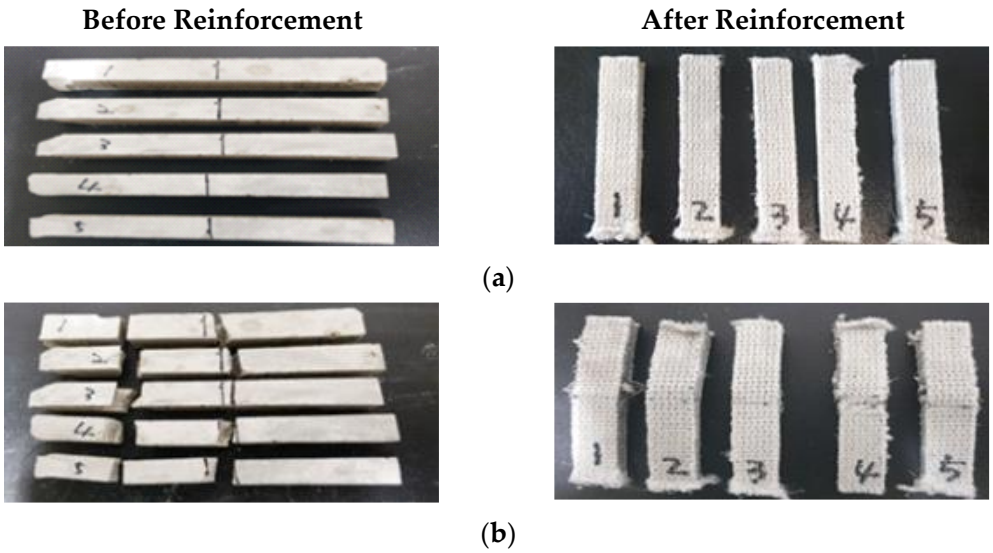


Figure 8. Free fall test result of double raschel GCCM; (**a**) before test, (**b**) after test.

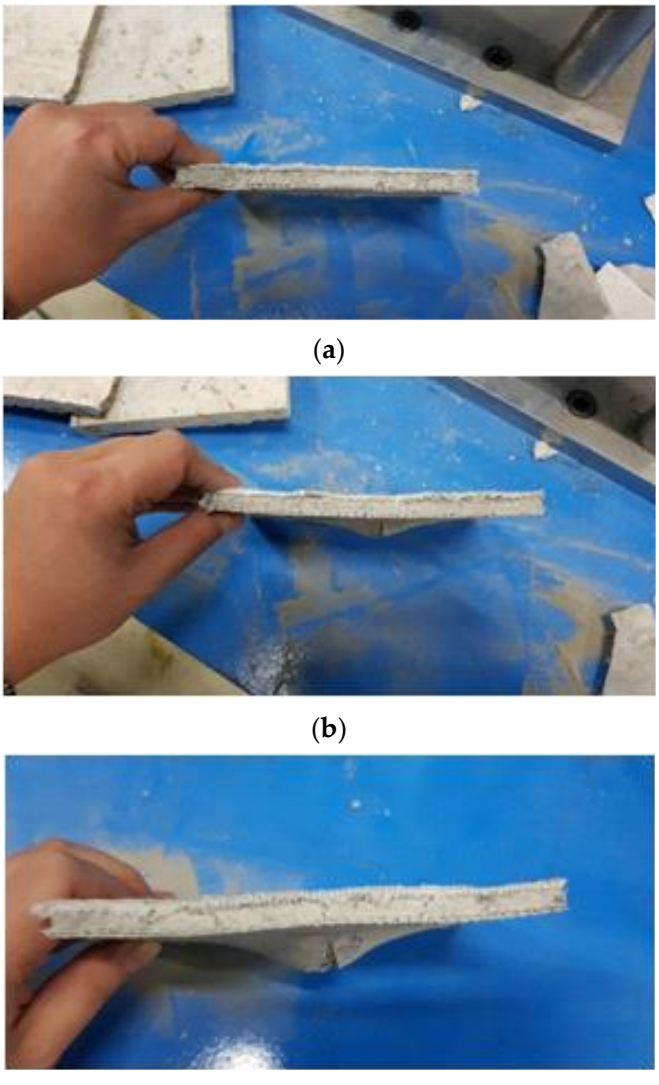


Figure 9. Free fall test result of double raschel GCCM; (**a**) 0.25 m, (**b**) 0.5 m, (**c**) 1.0 m.

Table 4. Impact test results of double raschel GCCM.

Test	Test No.	Thickness (mm)	Width (mm)	Impact Energy (kJ/m^2)
Before	1	15.14	12.40	80.67
	2	15.03	12.11	82.55
	3	15.22	12.04	82.18
	4	15.78	11.42	83.27
	5	15.61	11.00	87.42
	Average	15.36	11.79	83.22
	Standard Deviaton	0.2883	0.5095	2.2660
After	1	10.31	13.54	127.91
	2	10.42	13.68	127.65
	3	10.15	13.74	129.17
	4	10.17	13.65	129.38
	5	10.30	13.94	124.79
	Average	10.27	13.71	127.78
	Standard Deviaton	0.0994	0.1321	1.6411

The impact test results showed that the shock absorption rate of the double raschel GCCM reached 127.78 KJ/m^2, representing a significant increase compared to the pre-reinforcement value of 83.22 KJ/m^2. From this, it is seen that the double raschel GCCM is indeed suitable as a reinforcing material.

3.4. Bending Strength of Double Raschel GCCM with Curing Time

Typically, the curing period required to obtain the desired physical properties of concrete is around 28 days. However, in the scope of this study, the bending strength was assessed at two different curing periods: 10 days and 30 days, using the fast-setting cement. Table 5 shows the bending strength of double raschel GCCM with curing period. From this, it is seen that fast-setting cement can be effectively applied in double raschel GCCM applications, with a curing period of 10 days. Furthermore, this suggests the potential application of this material for emergency restoration purposes.

Table 5. Bending strength of double raschel GCCM with curing period.

Curing Period (Days)	Bending Strength (MPa)
10	6.60
30	9.29

The double raschel GCCM, when subjected to a 30-day curing period, showed excellent bending strength, reaching a value of 9.29 MPa. This improvement is attributed to the reinforcing influence of basalt fiber within the upper and lower textiles, thus contributing to the overall performance enhancement. From this, it is suggested that the integration of fast-curing cement with double raschel GCCM could potentially lead to a reduction in construction period while simultaneously achieving enhanced physical properties during field application.

3.5. Bending Strength under Environmental Condition

Table 6 shows the bending strength of the double raschel GCCM under environmental conditions. The bending strength exhibited in the presence of seawater did not show a significant tendency.

Table 6. Bending strength of double raschel GCCM under environmental conditions.

Environmental Condition	Curing Period (Days)	Bending Strength (MPa)	Retention of Bending Strength (%)
Seawater	0	9.29	97.8
	30	9.08	
Freezing and Thawing	0	9.29	65.9
	30	6.12	
Acidic (pH 4)	0	9.29	83.1
	30	7.72	
Alkaline (pH 12)	0	9.29	74.1
	30	6.88	

The freezing and thawing phenomena is attributed to the fact that the moisture present within the concrete during the repeated thawing cycles did not undergo proper curing, consequently giving rise to the formation of pores within the concrete as the freezing-thawing cycle continued, even under the challenging condition of ice, where concrete typically shows its weakest performance, the double raschel GCCM exhibited a bending strength of 6.12 MPa. Also, for the double raschel GCCM before and after undergoing acid and alkali treatment, a marginal decrease was observed after alkali treatment, while an increase was actually observed after acidic treatment. From this, it is seen that the marginal reduction in bending strength resulted from the influence of the polyester fiber, which is susceptible to the effects of the alkaline condition. Conversely, the impact under the acidic condition was not substantial, and in fact, a slight increase in bending strength was noted as the curing period extended.

4. Conclusions

In this study, a double raschel structure was employed to enhance the bending strength of GCCM. Bending strength was compared and analyzed alongside the concrete filling amount and foaming agent content. When the concrete filling amount was the same, the thickness of the double raschel GCCM increased with the addition of a blowing agent, but it was observed that cracks occurred on the surface due to concrete shrinkage during hydration. When a blowing agent was added, it was observed that as the concrete filling amount increased, the bending strength of the double raschel GCCM also increased, and, due to this, it can be inferred that the influence of concrete's tendency for brittle failure may be reduced. Additionally, when the double raschel GCCM was subjected to 30 days of treatment in seawater, freezing and thawing conditions, acidic, and alkaline conditions, the retention of bending strength followed the order: seawater > acidic > alkaline > freezing and thawing conditions. For the double raschel GCCM in seawater, there was almost no change in bending strength. However, under freezing and thawing conditions, there was a 35% reduction in bending strength. In acidic and alkaline conditions, there were reductions of 17% and 26%, respectively, in bending strength.

It can be seen that when expanding the application of double raschel GCCMs to purposes such as coastal erosion prevention, coastal protection, and slope reinforcement, the above results can be used as reference data.

Author Contributions: Conceptualization, S.K., J.Y. and H.J.; methodology, H.J.; validation, E.K. and D.L.; formal analysis, E.K.; investigation, E.K. and D.L.; data curation, H.J.; writing—original draft preparation, S.K. and J.Y.; writing—review and editing, S.K., J.Y. and H.J.; supervision, S.K., J.Y. and H.J.; project administration, H.J.; funding acquisition, H.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by a grant (20010999) from the Industrial Material Core Technology Research Program funded by the Ministry of Trade, Industry and Energy of the Korean Government.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Rokugo, K.; Kanda, T.; Yokota, H.; Sakata, N. Applications and recommendations of high performance fiber reinforced cement composites with multiple fine cracking (HPFRCC) in Japan. *Mater. Struct.* **2009**, *42*, 1197. [CrossRef]
2. Isley, F. The use of high performance textiles in construction projects. *J. Ind. Text.* **2002**, *31*, 205–221. [CrossRef]
3. Koeckritz, U.; Cherif, C.; Weiland, S.; Curbach, M. In situ polymer coating of open grid warp knitted fabrics for textile reinforced concrete application. *J. Ind. Text.* **2010**, *40*, 157–169. [CrossRef]
4. Colombo, I.G.; Magri, A.; Zani, G.; Colombo, M.; Prisco, M. Textile reinforced concrete: Experimental investigation on design parameters. *Mater. Struct.* **2013**, *46*, 1953–1971. [CrossRef]
5. Peled, A.; Cohen, Z.; Pasder, Y.; Roye, A.; Gries, T. Influences of textile characteristics on the tensile properties of warp knitted cement based composites. *Cem. Concr. Compos.* **2008**, *30*, 174–183. [CrossRef]
6. Peled, A. Strain hardening behavior of textile reinforced concrete (TRC). In *Proceedings of SHCC2-Rio Conference*; Filho, R.D.T., Silva, F.A., Koenders, E.A.B., Fairbairn, E.M.R., Eds.; RILEM Publications: Bagneux, France, 2011; pp. 45–52.
7. Barzin, M. *Mechanics of Fiber and Textile Reinforced Cement Composites*; CRC Press Taylor & Fancis Group: Boca Raton, FL, USA, 2011.
8. Hartig, J.; Häußler-Combe, U.; Schicktanz, K. Influence of bond properties on the tensile behaviour of textile reinforced concrete. *Cem. Concr. Compos.* **2008**, *30*, 898–906. [CrossRef]
9. Mishra, R.; Militky, J.; Pachauri, R.; Gupta, N.; Behera, B.K. Modeling and simulation of earthquake resistant textile structural concrete. *Compos. Part B Eng.* **2015**, *81*, 91–97. [CrossRef]
10. Mecit, D.; Roye, A. Investigation of a testing method for compression behavior of spacer fabrics designed for concrete applications. *Text. Res. J.* **2009**, *79*, 867–875. [CrossRef]
11. Roye, A.; Gries, T. 3-D textiles for advanced cement based matrix reinforcement. *J. Ind. Text.* **2007**, *2*, 163–173. [CrossRef]
12. Paulson, J.; Kohlman, R. *The Geosynthetic Concrete Composite Mat (GCCM) Current and Future Practices for the Testing of Multi-component Geosynthetic Clay Liners*; Stp 1562; ASTM International: West Conshohocken, PA, USA, 2013; pp. 146–154.
13. Han, F.; Chen, H.; Jiang, K.; Zhang, W.; Lv, T.; Yang, Y. Influences of geometric patterns of 3D spacer fabric on tensile behavior of concrete canvas. *Constr. Build. Mater.* **2014**, *65*, 620–629. [CrossRef]
14. Han, F.Y.; Chen, H.S.; Li, X.Y.; Bao, B.C.; Lv, T.; Zhang, W.L.; Duan, D.H. Improvement of mechanical properties of concrete canvas by anhydrite modified calcium sulfoaluminate cement. *J. Compos. Mater.* **2016**, *50*, 1937–1950. [CrossRef]
15. Jirawattanasomkul, T.; Kongwang, N.; Jongvivatsakul, P.; Likitlersuang, S. Finite element modelling of flexural behaviour of geosynthetic cementitious composite mat (GCCM). *Compos. Part B* **2018**, *154*, 33–42. [CrossRef]
16. Jirawattanasomkul, T.; Kongwang, N.; Jongvivatsakul, P.; Likitlersuang, S. Finite element analysis of tensile and puncture behaviours of geosynthetic cementitious composite mat (GCCM). *Compos. Part B* **2019**, *165*, 702–711. [CrossRef]
17. Jongvivatsakul, P.; Ramdit, T.; Ngo, T.P.; Likitlersuang, S. Experimental investigation on mechanical properties of geosynthetic cementitious composite mat (GCCM). *Constr. Build. Mater.* **2018**, *166*, 956–965. [CrossRef]
18. Xue, D.; Hu, H. Mechnical properties of biaxial weft-knitted flax composites. *Mater. Des.* **2013**, *46*, 264–269. [CrossRef]
19. Tsesarsky, M.; Peled, A.; Katz, A.; Anteby, I. Strengthening concrete elements by confinement within textile reinforced concrete (TRC) shells–static and impact properties. *Constr. Build Mater* **2013**, *44*, 514–523. [CrossRef]
20. Naaman, A.E. Evolution in ferrocement and thin reinforced cementitious composites. *Arab. J. Sci. Eng.* **2012**, *37*, 421–441. [CrossRef]
21. Armakan, D.M.; Roye, A. A study on the compression behavior of spacer fabrics designed for concrete applications. *Fibers Polym.* **2009**, *10*, 116–123. [CrossRef]
22. Lepech, M.D.; Li, V.C. Water permeability of engineered cementitious composites. *J. Cem. Concr. Compos.* **2009**, *31*, 744–753. [CrossRef]
23. Hegger, J.; Voss, S. Investigations on the bearing behaviour and application potential of textile reinforced concrete. *Eng. Struct.* **2008**, *30*, 2050–2056. [CrossRef]
24. Kim, Y.Y.; Kong, H.-J.; Li, V.C. Design of engineered cementitious composite suitable for wet-mixture shotcreting. *ACI Mater. J.* **2003**, *100*, 511–518.
25. Dooraki, B.F.; Nemes, J.A.; Bolduc, M. Study of parameters affecting the strength of yarns. *J. Phys.* **2006**, *134*, 1183–1188.
26. Zhu, D.; Gencoglu, M.; Mobasher, B. Low velocity impact behavior of AR glass fabric reinforced cement composites in flexure. *Cem. Concr. Compos.* **2009**, *31*, 379–387. [CrossRef]
27. Vassiliadis, S.; Kallivretaki, A.; Psilla, N.; Provatidis, C.H.; Mecit, D.; Roye, A. Numerical modelling of the compressional behaviour of warp-knitted spacer fabric. *Fibres Text. East. Eur.* **2009**, *17*, 56–61.
28. Zhi, C.; Du, M.; Sun, Z.; Wu, M.; He, X.; Meng, J.; Yu, L. Warp-knitted spacer fabric reinforced syntactic foam: A compression modulus meso-mechanics theoretical model and experimental verification. *Polymers* **2020**, *12*, 286. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.