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Manufacturing and Field Application Performance Evaluation of Cement-Filled Geotextile Composite (CFGC) for Ground Reinforcement

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ABSTRACT: A double Raschel cement-filled geotextile composite (CFGC) with enhanced structural elongation control and reinforcement strength was developed using the yarn-in-lay technique to incorporate reinforcing fibers. Inorganic basalt fibers were employed as reinforcements to improve the composite's durability and mechanical performance. To minimize cross-sectional shrinkage during concrete curing, the impact resistance of the double Raschel CFGC was optimized by adjusting the foaming agent content and the amount of concrete filling. The durability of the composite was subsequently evaluated by assessing the retention of bending strength under various environmental conditions, including freeze–thaw cycles, elevated temperature and humidity, and acidic and alkaline exposures.

KEYWORDS: Double Raschel CFGC, basalt fibers, yarn-in-lay technology, impact resistance, bending strength, durability

1 INTRODUCTION

The double Raschel cement-filled geotextile composite (CFGC) can be rapidly and conveniently installed through a simple hydration reaction. It exhibits excellent properties, including high load-bearing capacity, superior ductility, reduced thickness, light weight, and resistance to corrosion. The double Raschel CFGC is composed of an upper fiber layer for injecting dry cement powder, an intermediate layer that retains the powder, and a lower fiber layer that prevents material loss. Once the three-dimensional fiber matrix is filled with dry cement powder, the upper fiber layer is sealed with a PVC film, enabling immediate installation of the material as a finished product upon hydration.

In this study, a three-dimensional structure was designed using the yarn-in-lay technique, incorporating inorganic basalt fibers as reinforcement elements connecting the upper and lower fiber layers of the double Raschel CFGC. This configuration significantly improved structural elongation control and enhanced the mechanical performance of the composite. To address the brittle nature of the CFGC concrete, optimal foaming agent content and concrete filling amount were determined, and their effects on impact resistance and flexural strength were evaluated. Additionally, considering the environmental conditions during construction, the durability of the double Raschel CFGC was assessed under freeze–thaw cycles, high temperature and humidity, and acidic and alkaline environments, based on the retention of bending strength.

2 EXPERIMENT

2.1 *Manufacturing of doble raschel CFGC*

To develop a double Raschel CFGC optimized for its intended application, a three-dimensional 6-bar double Raschel structure was designed, as illustrated in Figures 1 and 2. The design considered the configuration of the upper textile layer to facilitate smooth filling of dry cement powder, provided sufficient thickness in the lower textile layer to support the cement powder, and ensured compactness to prevent material loss. Furthermore, to control structural elongation, loops were formed in the warp direction using the yarn-in-lay technique, in which basalt fibers were incorporated as reinforcing elements.

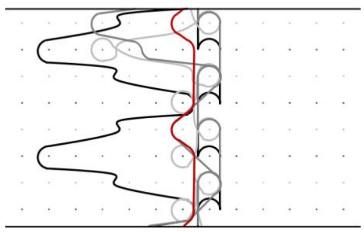


Figure 1. Warp knit structural design of double raschel using 'yarn in lay' technology (6bar).

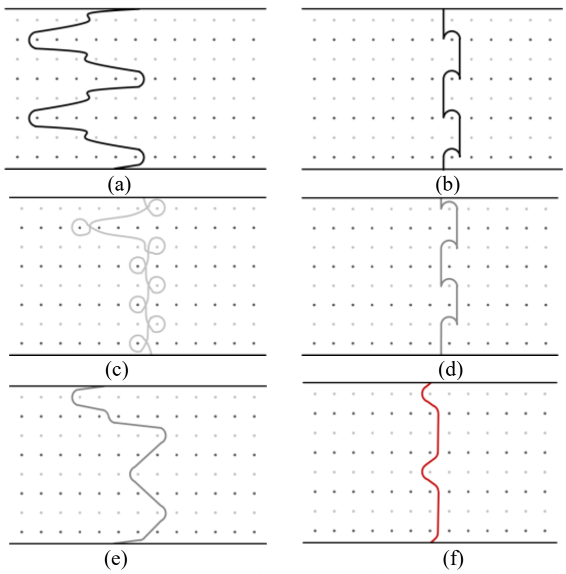


Figure 2. Lapping arrangement for each guide bar of double raschel warp knit structure (6bar);
(a) L1, (b) L2, (c) L3, (d) L4, (e) L5, (f) L6.

After the dry cement powder was filled, a film was attached by heat treatment using a hot-melt adhesive, resulting in the fabrication of the three-dimensional double Raschel CFGC, as shown in Figure 3.

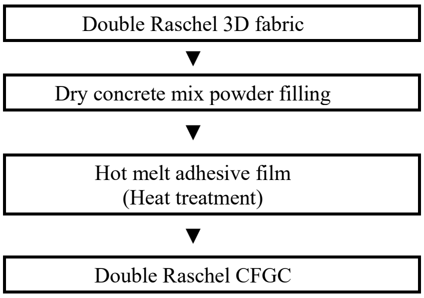


Figure 3. Schematic diagram of double raschel CFGC manufacturing.

To assess the knitting feasibility of the double Raschel structure and the effect of basalt fiber reinforcement on tensile strength, multiple specimens were fabricated, and tensile strength tests were conducted. Among them, the double Raschel CFGC specimen shown in Figure 4 was selected for detailed evaluation in this study.

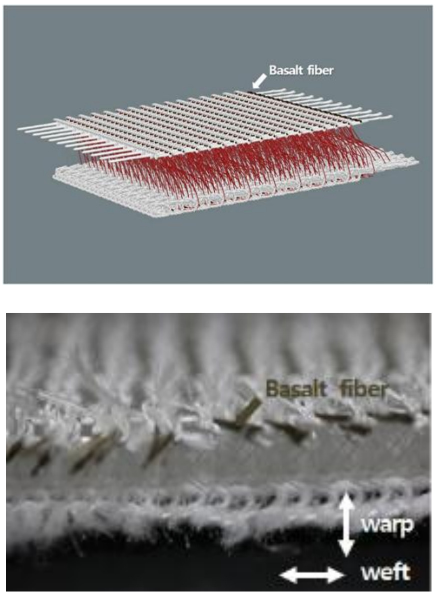


Figure 4. Photographs of designed double raschel CFGC structure.

2.2 *Evaluation of doble raschel CFGC characteristics*

The Portland cement used for filling the double Raschel CFGC was a rapid-hardening blend, consisting of 55% tricalcium silicate (C_3S), 19% dicalcium silicate (C_2S), 10% tricalcium aluminate (C_3A), 7% tetracalcium aluminoferrite (C_4AF), 2.8% magnesium oxide (MgO), 2.9% sulfur trioxide (SO_3), 1.0% loss on ignition, and 1.0% free lime (CaO).

The durability of the double Raschel CFGC under freeze–thaw condition was evaluated by subjecting the specimens to cyclic freezing at –15°C and thawing at room temperature over a period of 30 days (one cycle per day). Bending strength was measured before and after the test to assess degradation. For high temperature and humidity conditions, specimens were cured at 40°C and 70% relative humidity for 30 days, and changes in bending strength were similarly measured to evaluate durability.

In addition, chemical resistance was evaluated by measuring changes in bending strength after immersing the double Raschel CFGC specimens in acidic (pH 4) and alkaline (pH 12) solutions at 50°C for 30 days.

Since shrinkage caused by cement hydration can significantly affect the final properties of the double Raschel CFGC, the optimum foaming agent content and concrete filling amount were determined to minimize cross-sectional shrinkage. The foaming agent was tested at weight ratios of 1%, 3%, 5%, 7%, 9%, and 11%, while concrete was filled in amounts of 530g, 620g, and 71g. The highest bending strength of the double Raschel CFGC was achieved under these optimized conditions.

3 RESULTS AND DISCUSSION

3.1 *Bending strength according to foaming agent content and concrete filling amount*

To mitigate cross-sectional shrinkage caused by concrete contraction during the hydration process of the double Raschel CFGC, foaming agents were incorporated at concentrations of 1, 3, 5, 7, 9, and 11wt%. Volume changes were measured after a 30-day curing period.

Although the overall concrete volume increased with higher foaming agent content, the optimal concentration was identified as 5wt%, which resulted in the greatest volume expansion without inducing surface cracking, as illustrated in Figure 5.

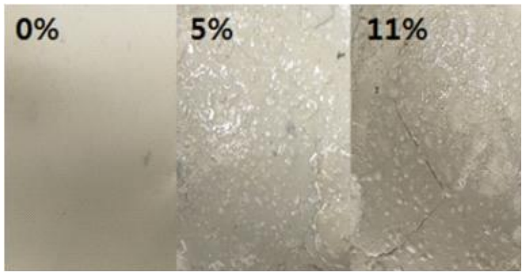


Figure 5. Photographs of surface change of concrete with foaming agent content.

As shown in Table 1, the concrete exhibited a bending strength of approximately 9.29 MPa after 30 days of curing. Under the same curing conditions, the double Raschel CFGC demonstrated comparable bending strength, reaching 9.29 MPa. This enhancement is attributed to the reinforcing effect of basalt fibers incorporated within the upper and lower textile layers, which contributed to the overall mechanical performance improvement.

These results suggest that integrating fast-curing cement with the double Raschel CFGC may reduce construction time while simultaneously enhancing physical properties in field applications.

Table 1. Bending strength of double raschel CFGC with curing period.

Curing periods(days)	Bending strength (MPa)
10	6.60
30	9.29

Under the optimal foaming agent content, the concrete filling amounts in the double Raschel CFGC were set to 530g, 620g, and 710g, respectively. After curing for 30 days, bending strength tests were performed. As shown in Table 2, bending strength increased with higher concrete filling amounts.

However, microscopic air voids were observed within the concrete at the 530 g and 620 g filling levels, which may have contributed to the premature failure of the double Raschel

CFGC specimens. Consequently, a concrete filling amount of 710 g was identified as optimal.

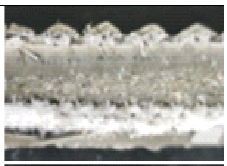
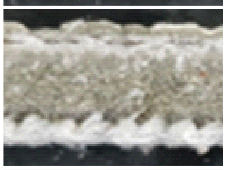
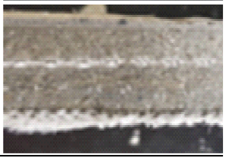
Table 2. Bending strength of double raschel CFGC with concrete filling amount.

Curing periods(days)	After foaming agent treatment		
Concrete filling content (g)	530	620	710
Bending strength (MPa)	3.21	4.32	5.98

Cross-sectional images of the double Raschel CFGC were analyzed, and comparisons were made between specimens before and after the addition of the optimal foaming agent content, as summarized in Table 3.

The results indicate that cross-sectional reduction caused by concrete shrinkage during hydration was mitigated by the incorporation of the foaming agent, even at equivalent concrete filling levels.

Table 3. Photographs of cross section of double raschel CFGC with optimal foaming agent content.

Concrete filling amount (g)	Optimal foaming agent content: Before	Optimal foaming agent content: After
530		
620		
710		

3.2 *Impact and Bending Strength Analysis.*

To evaluate the reinforcement effect against brittle fracture in conventional concrete, both ordinary concrete and double Raschel CFGC specimens were cured for 30 days.The double Raschel CFGC was fabricated using the optimized concrete filling amount in combination with 5wt% foaming agent content.

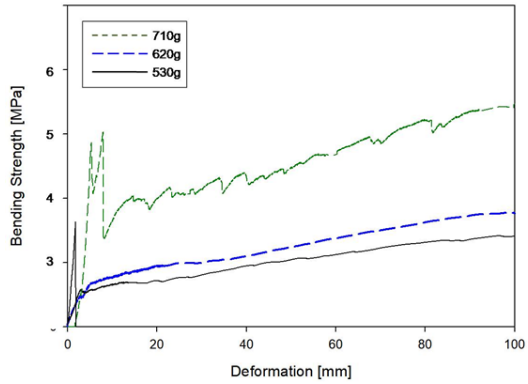
As presented in Table 4, impact test results showed that the impact absorption capacity of the double Raschel CFGC reached 127.78 kJ/m², representing approximately a 1.5-fold increase compared to the 83.22 kJ/m² measured for unreinforced concrete. for unreinforced concrete.

Table 4. Impact test results of double raschel CFGC.

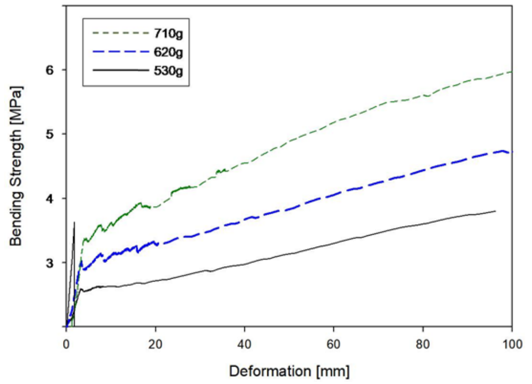
	Impact energy (kJ/m^2)
Before	83.22
After	127.78

Figure 6a illustrates the relationship between bending strength and the filling factor, while Figure 6b presents the bending strength at the optimal foaming agent content under equivalent concrete filling conditions.

Regardless of the presence of the foaming agent, bending strength exhibited a clear increasing trend with higher concrete filling amounts. Notably, when the concrete filling factor exceeded 100%, the increase in bending strength surpassed 160%. These results suggest that a concrete filling rate exceeding 100% is essential for the inherent physical properties of the double Raschel CFGC to be effectively manifested.



(a) Before



(b) After

Figure 6. Bending strength–deformation curves of double raschel CFGC at optimal foaming agent content.

As shown in Table 5, impact resistance tests were conducted on Portland cement concrete and double Raschel CFGC specimens, both cured for 30 days, to evaluate the reinforcement effect on the brittle fracture behavior of concrete.

The impact absorption capacity of the double Raschel CFGC was 127.78 kJ/m², which is approximately 1.5 times higher than the 83.22 kJ/m² observed for unreinforced concrete.

Table 5. Impact test results before and after double raschel CFGC

	Thickness (mm)	Breakage (J)
Before	15.36	15.05
After	10.27	17.99

3.3 *Durability in freeze and thaw environments*

Concrete, as a brittle material, is particularly susceptible to shrinkage cracking in environments subjected to repeated freeze–thaw cycles. This study investigated the durability of concrete under such conditions, simulating seasonal transitions from winter to spring.

The bending strength results of the thawed double Raschel CFGC are presented in Table 6. A slight decrease in bending strength was observed compared to the cured double Raschel CFGC. This reduction is presumed to result from residual moisture within the concrete, which, during repeated thawing, did not fully cure and led to pore formation.

Nevertheless, the double Raschel CFGC demonstrated sufficient performance even under thawed conditions, addressing a critical vulnerability commonly associated with conventional concrete.

Table 6. Bending strength of double raschel CFGC under freeze and thaw environmental condition.

Environmental condition	Curing period (days)	Bending strength (MPa)	Retention of bending strength (%)
Freeze and thaw	0	9.29	65.9
	30	6.12	

3.4 *Durability in high temperature and humidity environments*

Considering the high temperature and humidity conditions expected during the application of the double Raschel CFGC, the concrete was cured for 30 days at 40°C and 70% relative humidity.

As shown in Table 7, the bending strength of the CFGC slightly increased under these conditions after the 30 days curing period. This enhancement is attributed to the continuous moisture availability, which facilitates more effective hydration of the cement.

Therefore, it can be concluded that the double Raschel CFGC is capable of achieving its full mechanical performance in high temperature and humidity environments, comparable to that observed under standard curing conditions, without any deterioration in properties.

Table 7. Bending strength of double raschel CFGC under high temperature and humidity environmental condition.

Environmental condition	Curing period (days)	Bending strength (MPa)	Retention of bending strength (%)
High temperature and humidity	0	9.29	94.1
	30	8.74	

3.5 *Durability under acidic and alkaline environments*

The durability of the double Raschel CFGC in acidic and alkaline environments was evaluated by immersing specimens, cured for 10 days, in solutions with pH values of 4 and 12, respectively.

Bending strength was measured after 56 days of exposure at 50°C. No visible deformation was observed on the surface of the specimens following acid or alkaline treatment. As shown in Table 8, a slight decrease in bending strength was noted under alkaline conditions, whereas a modest increase was observed after acid exposure.

The reduction in bending strength in alkaline environments is likely due to the susceptibility of polyester fibers to alkaline degradation. In contrast, the acid environment had minimal impact, and the extended curing time may have contributed to the observed improvement in strength.

Table 8. Bending strength of double raschel CFGC under acid and alkaline environmental condition.

Environmental Condition	Curing period (days)	Bending strength (MPa)	Retention of bending strength (%)
Acidic (pH4)	0	9.29	83.1
	30	7.72	
Alkaline (pH 12)	0	9.29	74.1
	30	6.88	

These results indicate that the bending strength of the double Raschel CFGC is suitable for applications in both acidic and alkaline environments. Despite a slight reduction due to alkaline exposure, the specimens retained approximately 94.3% of their bending strength compared to untreated samples, demonstrating substantial durability.

4 CONCLUSIONS

The application of the double Raschel CFGC in this study underscored the importance of a three-dimensional structural design that facilitates cement filling in the upper textile layer, prevents cement loss in the lower textile layer, and provides sufficient space in the intermediate layer to retain cement powder. Basalt fibers were incorporated to enhance reinforcement strength, and yarn-in-lay technology was employed to achieve rigid fiber weaving without compromising loop formation, thereby controlling the structural elongation of the double Raschel CFGC. The double Raschel CFGC exhibited bending strength approximately twice that of conventional concrete after only 10 days of curing, and demonstrated durability under freeze–thaw cycles, high temperature and humidity, as well as acidic and alkaline environments.

As described above, the double Raschel CFGC exhibited behavior characteristic of flexible concrete, representing an ideal fiber–concrete interaction. These results suggest its potential for expanded applications in geotechnical engineering, including emergency restoration of sinkholes and control of erosion and coastal degradation.

5 ACKNOWLEDGEMENTS

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