Review of Carbon Fiber Composite Grid with Manufacturing and Design Concepts for Seismic Resistance

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Manuscript submitted October 16, 2019; accepted June 8, 2020.
doi: 10.17706/ijmse.2020.8.3.74-80.

Abstract: To fabricate the carbon fiber composite grid for seismic performance reinforcement, carbon fiber composite yarn with appropriate stiffness and ductility was fabricated and the optimum structure of the grid was designed and tested. Composite fiber of carbon fiber/aramid fiber/high strength polyester fiber was fabricated by double covering process, and the strength was increased by about 0.5% compared with carbon fiber which is matrix material. The TPU (thermoplastic polyurethane) extrusion coating method was more suitable for the carbon fiber composite yarn than urethane impregnation for the coating process. Creep properties of hybrid grid fabric of carbon fiber composite yarn during a simulated seismic event were evaluated using the SIM creep test method.

Key words: Carbon fiber composite grid, seismic performance, double covering, SIM creep test method.

1. Introduction

In general, reinforcement method used for steel structure is steel plate reinforcement method, which reinforces the structure by connecting reinforcement to base metal. However, this method has disadvantages in that the weight increases due to the reinforcing material and the workability is poor. Fiber reinforcement method is preferred over steel reinforcement method. Also, fiber reinforcement method is one of the seismic performance reinforcement methods, and has advantages such as light weight of the material, convenience of construction, and various forms according to the fiber material and physical properties. [1]-[4] Carbon fiber has characteristics such as high strength, high elasticity, light weight, excellent durability and method, and waterproof effect, but it is not suitable for use as seismic reinforcement due to brittleness due to high rigidity. On the other hand, aramid fiber-reinforced composites have lower strength than carbon fiber composites, but elongation is about 40%, which is known to exhibit soft behavior rather than brittle behavior. [5]-[9] Carbon fiber composite grid fabric can be used as a uni-directional or bi-directional load member depending on the high strength and structure of the carbon fiber, so that no additional process is required and the facility investment cost is reduced. However, depending on various factors such as the selection of suitable elasticity carbon fibers of appropriate physical properties, the optimization of weaving preparation process such as mixing hybrid type material with high ductility, the composition of coating resin and coating condition, appropriate manufacturing techniques are very important because they change significantly. [10]-[12] In this study, we fabricated carbon fiber composite yarn with appropriate stiffness and ductility and manufacture the hybrid grid for seismic resistance by strengthening and designing to have an optimum grid structure.

2. Experimental

2.1. Preparation of Hybrid Grid

Composite yarn for hybrid grid fabric is made of carbon fiber (; 12K T700-50C, 897.2 N) as a main material, and high strength polyester (PET; polyethylene terephthalate) fiber (1000 denier, 116.6 N) and aramid fiber (1000 denier, 325.0 N) which can complement the ductility of carbon fiber are used as the sub materials. The carbon fiber composite yarn was made by the double covering process. The fineness, tensile strength and elongation were measured to investigate the physical properties of the composite yarn manufactured after this.

2.2. Formation of Carbon Composite Yarns

The aramid fiber and the high-strength PET fiber were used as the core yarn, the aramid yarn yarn, and the yarn twisted yarn for double covering as shown in Fig. 1. In order to smooth the covering works for aramid fiber and high strength PET fiber. For the morphological stability of the carbon fiber composite yarn produced by the double covering process, the coating molding process was carried out. In order to investigate the more suitable process, the strength of carbon fiber composite yarn was coated by TPU (thermoplastic polyurethane) extrusion method.

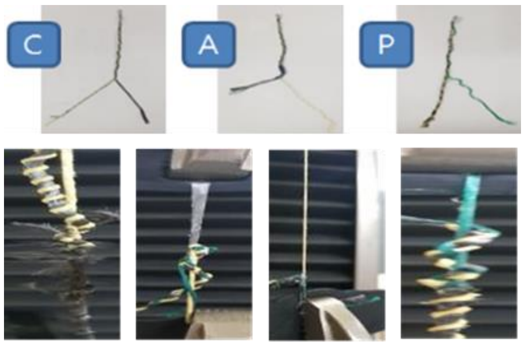
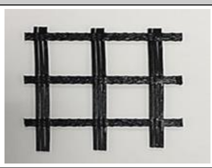
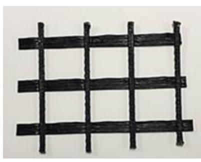
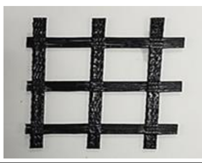
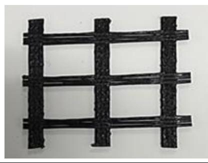


Fig. 1. Double Covering (C-carbon fiber, A-aramid fiber, P-polyester(PET) fiber).

2.3. Design of Grid Fabrics

Prior to the fabrication of the hybrid grid, we designed three unidirectional and one bidirectional grid fabrics as shown in Table 1.

Table 1. Hybrid Grid Fabric Structure Design Condition

	UD_1	UD_2	UD_3	BD_1
Hybrid Grid				

Composition		Specification	Warp fineness(denier)	Weft fineness(denier)
Unidirectional	UD_1	8000×250×250	4000	510
	UD_2	10000×250×250	4000	612
	UD_3	24000×250×250	4000	384
Bi-directional	BD_1	7000×250×250	4000	573

(where MD and CMD mean machine and cross machine directions, respectively.)

2.4. Seismic Resistance by SIM (Step Isothermal) Creep Test

10 ton/m grid fabric (U-2) which is widely used as reinforcement grid in Korea was used for seismic resistance by the SIM (stepped isothermal method) as a creep test. Five isothermal exposures of 23, 37, 51, 65, 79 °C were employed for the SIM procedure. The creep tests were performed at 40, 50 and 60% of ultimate tensile strength (UTS). To simulate a seismic event, tensile loads of 80, 90 and 100% of the UTS were applied during the 23 °C step and after the 79 °C step. The additional load was applied for a period of 1min and released. SIM creep test conditions are summarized in Table 2.

Table 2. SIM Creep Tests Conditions

Test Item	Condition
Temperature (°C)	23, 37, 51, 65, 79
Loading level (% of Ultimate strength)	40, 50, 60
Isothermal duration	3 hrs
Seismic loading level (% of Ultimate strength)	80,90,100
Seismic duration	1 min

3. Results and Discussion

3.1. Mechanical Properties of Carbon Composite Yarns

The reinforcing principle of concrete through fiber was examined to select evaluation items for carbon fiber composite yarns. Generally, fiber reinforced concrete is used to supplement low tensile strength and brittleness of concrete using fiber. The fibers added for reinforcement increase the strength of the concrete, control cracking and compensate the behaviour of the concrete after cracking. It is also possible to supplement the brittleness of the concrete by providing ductility to resist the stress applied in the cracked state. The carbon fiber composite yarn manufactured in this study plays a role of reinforcing as above, and therefore, the evaluation focuses on evaluating the tensile properties of the carbon fiber composite yarn. ASTM D3039 test method was used for the evaluation, and a number of yarns, not one yarn, were evaluated as specimens with an emphasis on the stability of the evaluation results. Fig. 2 shows the carbon fiber composite yarn after the double covering process. The elongation of the carbon fiber used was 2.1%, and the elongation was increased by about 0.5% due to the covering process, and the strength was also greatly increased.

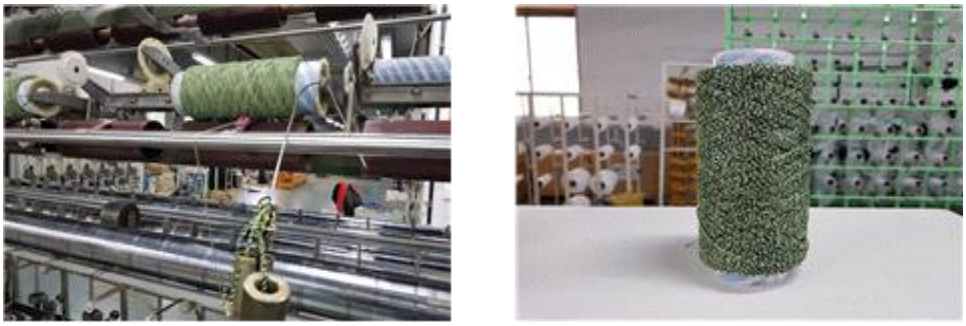


Fig. 2. Carbon fiber composite yarn for grid fabric manufacturing.

As a result of impregnation with the resin, the shape of the resin changed from a flat shape to a round shape as the coating amount of the resin increased. It was confirmed that the softness of the softness was appropriate, and then the simple nozzle was evaluated according to the content of the soft coating agent. The solution was prepared in four kinds of 25%, 50%, 75%, 100%, and as a result, it was confirmed that as the content was increased, a lot of resin was generated on the fiber surface after coating. As a result, 25% solution is most suitable.

3.2. Mechanical Properties of Grid Fabrics

The strength and elongation of the above four grids designed to derive the optimal fineness and fabric structure required for the fabrication of the reinforcing grid were measured and the values are shown in Fig. 3. Overall, the slope intensity was greater and the elongation was higher. UD_3, UD_2, UD_1, and BD_1 were the strengths of the weft yarns in all four samples. The tensile strength of UD_3 specimen was about 1.8 times greater than that of the other specimens. The tensile strength of BD_1 was about 1/4 of that of UD_3. The tensile strength of this slope is in agreement with the order of slope thickness of each specimen. There was no significant difference in elongation as tensile strength, but there was a big difference in the weft direction than in the warp direction. UD_1 and UD_2 have similar weft direction elongation, but UD_3 and BD_1 have smaller values. All of the four specimens used wefts of the same conditions, and the difference in the structure of each specimen can be interpreted as the difference in the structure of the grid. Comparing the tensile strength and elongation, it can be concluded that the thicker the fiber, the stronger the tensile strength can be obtained, and the structure of specimen UD_1 and UD_2 can be considered to be favorable to the weft direction elongation. However, UD_3 has the highest elongation in the sloping direction, so it is important to choose the proper structure depending on the situation. On the other hand, the specimen of BD_1 exhibited lower physical properties than the specimens with other unidirectional structures in both strength and elongation. As a result, it can be concluded that the bidirectional structure has no great advantage and that the unidirectional structure is a more stable grid fabric.

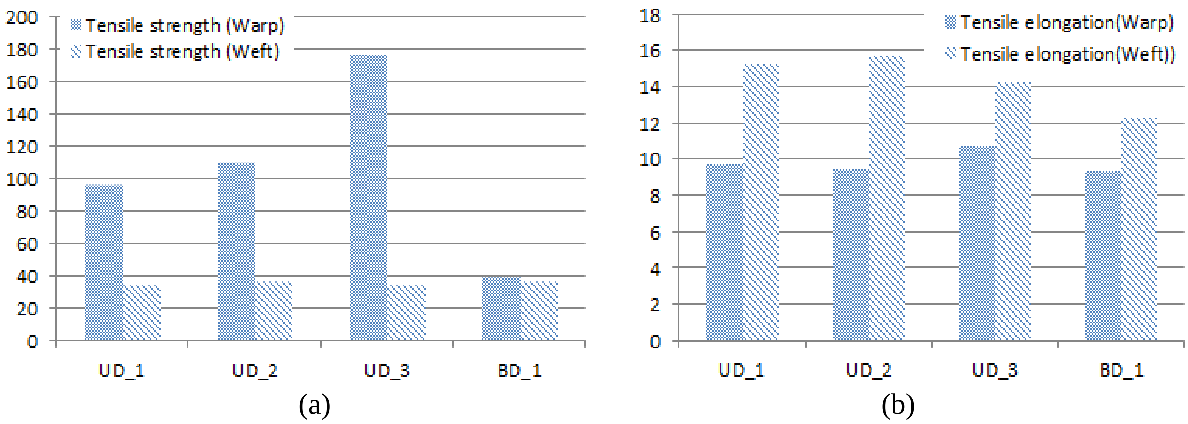


Fig. 3. Tensile strength (a) and tensile elongation (b) of specimen.

3.3. Seismic Resistance of Grid Fabrics

Fig. 4 shows creep strain vs. log time at various stress conditions. The creep strain increases linearly with log time and creep rupture was detected at 70-100% applied loads. After graphically showing the result of creep rupture with applied stress over rupture time, the applied stress at 106 hours of design term was obtained through regression analysis and the reduction factor was obtained by the comparison of this value with the UTS.

Fig. 5 shows regression analysis diagram. It is observed that the data follows a linear trend and the reduction factor was 1.55. The creep response resulting from the application of the seismic load midway through the 23°C temperature step is shown in Fig. 6(a). Temperature was gradually increased from 23°C to 79°C and the seismic load produced an immediate strain of approximately 5.6% at initial stage. At this moment, the strain recovery is 2.6% after removal the creep load. It is apparent that there is no effect on the creep response after 1.5 hour without regard to temperature till 79°C. The final strain was approximately 8%. The creep response of the application of the seismic load after the 79°C temperature is shown in Fig. 6 (b). Creep strain exhibits an initial decrease at each elevated temperature step. This behavior is most likely caused by the thermal shrinkage of the PET filament. The final strain was approximately 7.9%, similar value as that obtained from the application of the seismic load midway through 23°C temperature step. Creep strain slightly decreased at 40% of UTS until reaching the 65°C step, after seismic event and began to increase after the 79°C step. Creep strain rate is very slow after the seismic event, so the recovery force leads to long-term shrinkage. Creep strain slightly decreased at 50% of UTS until 103 hours, after which it increased. Temperature was gradually increased from 23°C to 79°C and the seismic load produced an immediate strain of approximately 5.6% at initial stage. At this moment, the strain recovery is 2.6% after removal the creep load. It is apparent that there is no effect on the creep response after 1.5 hour without regard to temperature till 79°C. The final strain was approximately 8%. The creep response of the application of the seismic load after the 79°C temperature is shown in Fig. 6(b).

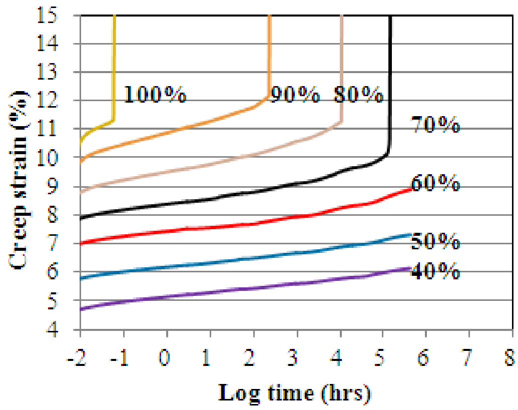


Fig. 4. Creep properties of WG-10.

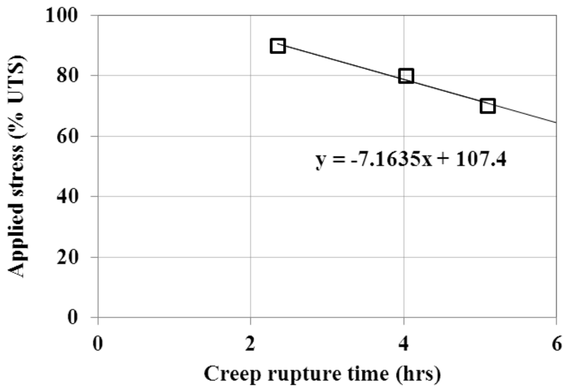


Fig. 5. Plot of applied stress vs. creep rupture time.

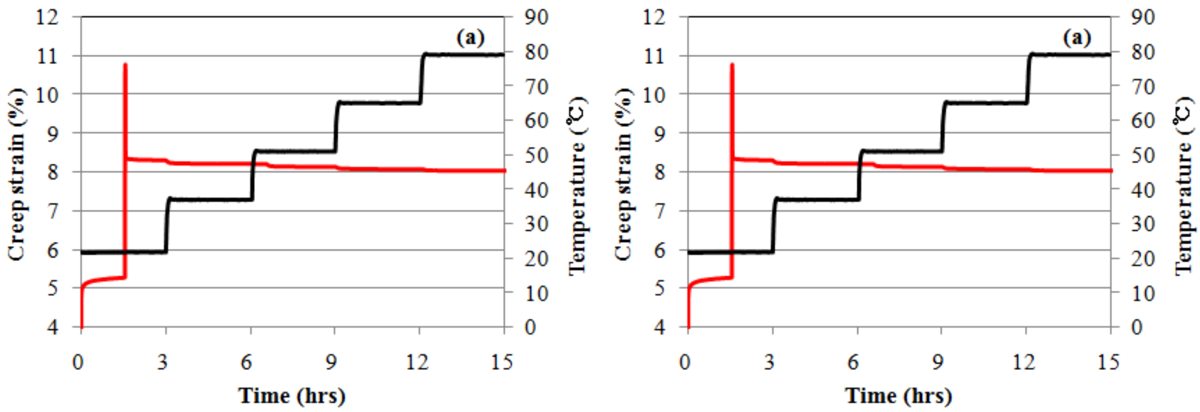


Fig. 6. Creep response vs. linear time recorded for a seismic SIM test; (a) 100% of UTS applied for 1 min midway through the 23°C temperature step (b) 100% of UTS applied for 1 min after the 79°C temperature step.

Creep strain exhibits an initial decrease at each elevated temperature step. This behavior is most likely caused by the thermal shrinkage of the PET filament. The final strain was approximately 7.9%, similar value as that obtained from the application of the seismic load midway through 23°C temperature step. Creep strain slightly decreased at 40% of UTS until reaching the 65°C step, after seismic event and began to increase after the 79°C step. Creep strain rate is very slow after the seismic event, so the recovery force leads to long-term shrinkage. Creep strain slightly decreased at 50% of UTS until 103 hours, after which it

increased. Creep strain rate at 50% UTS occurs at a greater rate than observed in the test at 40% of UTS after same seismic event. The time for shrinkage rebound for the test at 50% of UTS is shorter than that for the test at 40% of UTS. In contrast, creep strain increased at 101 hours for the test at 60% of UTS.

4. Conclusion

In this study, to fabricate a hybrid grid for seismic performance reinforcement, carbon fiber composite yarn with appropriate stiffness and ductility was fabricated and the optimum structure of the grid was designed and checked. Composite fiber of carbon fiber / aramid fiber / high strength PET fiber were fabricated by double covering process, and the strength was increased by about 0.5% compared to carbon fiber. The TPU extrusion method was more suitable for the strength and stability of the fiber than the urethane impregnation in the coating process for the morphological stability of the composite fiber. In order to obtain the optimal fineness and grid structure for applying the carbon fiber composite yarn to the hybrid grid, the larger the thickness of the fiber used, the stronger the strength was. Compared to unidirectional grid, UD_1 and UD_2 structures showed favorable elongation in weft direction and UD_3 structure showed favorable elongation in sloping direction. On the other hand, when comparing strength and elongation, the bi-directional grid did not show much advantage compared to unidirectional grid, but further study is needed for this part. In the future research, we will apply the fabricated carbon fiber composite yarn directly to the hybrid grid fabric, and evaluate the mechanical properties and seismic performance of the carbon fiber composite to improve the seismic performance of the hybrid composite. Creep properties of geogrids during a simulated seismic event were evaluated using the SIM test method. Creep strain decreased after seismic event cause of recovery force, after that strain increased again. After same condition of seismic event in different times, strain finally overlapped. Normally, seismic event has no effect on long-term property but in specific condition, a seismic event may reduce the creep property of grid fabric.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Dr. Han-Yong Jeon wrote this paper and progressed this research; Mr. Yan Yu and Mr. A Ram Lee tested and analyzed the experimental data of this research.

Acknowledgement

This research was supported by a grant (10083576) from Industrial Material Core Technology Research Program funded by Ministry of Trade, Industry and Energy of Korean government.

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