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Carbon Emission Reductions of GFRP Reinforced Concrete Bridges in Replacement of Steel Rebars

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Abstract*— In this study, the possibility of reducing carbon emission of GFRP rebars that can replace existing steel rebars, which are traditional construction materials, was analyzed. The analysis method was to compare the total carbon emission according to the use of GFRP rebars compared to the existing rebar usage based on the final object by integrating the carbon emission of each material production stage and transport stage. From the research results, it was analyzed that carbon emissions of about 66.8% based on the final target can be reduced even when only carbon emissions in the production and transport stage are calculated. Therefore, the active application of GFRP rebars in the construction industry is expected to provide environmental benefits such as securing durability of structures and reducing carbon emissions. In addition, due to the small unit weight compared to the existing material, steel rebar, it is expected to gain additional benefits such as improved energy usage and worker convenience in transportation and on-site installation work.

***Index Terms*—GFRP rebar, carbon emission reduction, precast bridge deck, environmental benefit.**

I. INTRODUCTION

Carbon emissions from road structure construction also occur in the production and transportation of materials, equipment operation at construction sites, and in the use and maintenance stages, but are most frequently generated in the material production stages. Therefore, this study examines the possibility of carbon emission reduction of construction materials using alternative materials by analyzing the carbon emission effect of the glass fiber reinforced polymer (GFRP) rebar that can replace steel rebar, one of the most commonly used materials for road structure construction [1].

Various efforts were made to apply FRP composite materials to construction due to their excellent weight-to-weight strength and corrosion-free properties. In particular, FRP rebars, which can be used as steel rebar replacement materials, began to be introduced in the late 1970s in North America. In general, GFRP rebars are known to be advantageous in terms of maintenance and structure life as they can replace reinforcement with weight of about 1/4 compared to existing steel reinforcement and tensile strength of twice as much as steel reinforcement. In addition, due to its light weight characteristics, it is expected to be useful in reducing carbon emissions as it can reduce equipment usage in the process of material production, transportation, and construction sites. In order to analyze the carbon emission effect of materials, construction methods, and equipment required for road structure construction, a method of calculating individual carbon emission units by applying them to usage is generally used. Therefore, in order to analyze the carbon emission effect of GFRP rebars, this study intends to consider the procedure of integrating and comparing the total carbon emission throughout the production and transport stages for carbon emission units of each material and final object [2-3].

Life Cycle Assessment (LCA) from production to disposal is required to analyze all environmental factors, but this study aims to analyze the impact of carbon emissions from the production and transportation stages of existing materials (steel rebar) and GFRP rebar [4]. This is because the above materials are combined with concrete to become the final object, and it is difficult to compare the energy usage during subsequent field work, and the carbon emissions generated during maintenance and use stages and the life of the final object are currently lacking verified data.

II. ANALYSIS METHOD OF CARBON EMISSION EFFECT OF GFRP REBAR

In this study, a method was derived to compare and analyze the carbon emission effects of each material, and the analysis procedure as shown in Table 1 was established by referring to previous studies. This is based on the LCA basic frame according to ISO 14040:2006, and the carbon emission source unit for each material in the list analysis stage can be analyzed by using the existing LCI DB or by separately presenting a calculation method if the DB does not exist.

Carbon emission impact analysis was performed in the following manner.

(1) Analysis of carbon emission effects in the production

The comparison value of carbon emission in the production stage according to the input weight of each material is analyzed.

Example

The total weight of rebars required for the same end object (total 350m barrier of 1m height) is 16,014kg, and the total weight is 4,042kg when replaced by GFRP reinforcing bars, which can be reduced by 74.8% compared to steel rebars.

Carbon emissions from the production stage of each material required for the final object are 42,918 kgCO2eq of steel rebar and 13,460 kgCO2eq of GFRP reinforcement, which can reduce carbon emissions by 29,458 kgCO2eq (68.6%).

Table 1. Carbon emission effect analysis procedures and methods

First stage Selection of analysis targets	◦ Selection of final object to be analyzed ◦ Total amount data of materials to be put into the final object is required (calculation details, etc.)
▼	
Second stage Calculation of carbon emission unit by material	◦ Quote if you have LCI DB (up-to-date data first) ◦ If there is no LCI DB, it is necessary to calculate the carbon emission unit of 'raw material and production stage'
▼	
Third stage Carbon emission integration by material	◦ Production stage: Carbon emission unit by material × total input volume (kg) ◦ Transportation stage: Truck carbon emission factor × same distance × total transport (kg) ※ Except for the stages of construction, maintenance, use, and disposal
▼	
Fourth stage Carbon emission effect comparison	◦ Analysis of contribution to carbon reduction using total carbon emission by material
▼	
Fifth stage Sensitivity Analysis	◦ Check for sensitivity analysis according to changes in input values

(2) Carbon Emission Impact Analysis of Transport Stage

The comparison value of carbon emission in the transport stage according to the input weight of each material is analyzed.

Example

Carbon emissions from steel bars 19kgCO2eq when compared to the same standard (70km/h, 20km/h) for the production of the final object (1m total barrier 350m) and carbon emissions of 14kgCO2eq can be reduced (73.7%) with 5kgCO2eq when replaced by GFRP rebars.

GFRP is high in the production stage, but only carbon emission unit of the truck according to the total transport weight is applied in the transport stage, so the carbon emission reduction rate is similar to that of the material weight reduction (74.8%).

Due to the large gap between carbon emissions in the production stage (0.04~0.05% compared to the production stage), it is unlikely that there will be a significant impact on the comparison of total carbon emissions even if excluded from the integration.

Based on the above, the carbon emission impact of GFRP reinforcement muscles was comprehensively analyzed.

III. ANALYSIS EXAMPLES

An integrated EX girder bridge was established as an analysis target for comparing carbon emissions of the existing material, reinforcing bars of GFRP using alternative materials. Among the upper structures of this bridge under construction in South Korea, precast decks and barriers were selected as the final targets.

Carbon emissions were analyzed for the total input weight of steel rebars required for the final object and the total input weight when it was replaced with a GFRP rebar. At this time, the carbon emission source units of each material used were 2.68kgCO2eq/kg of steel rebar and 3.33kgCO2eq/kg of GFRP rebar, which were suggested based on the Inventory of Carbon Energy database (UK) in previous studies [5], and 24.3% more carbon was emitted in the production stage.

Since the unit weight according to the diameter of each material extracted from the quantity calculation statement differs in the relative ratio, the carbon emission also differed according to the diameter and usage of the steel rebars and GFRP rebars used for each object. Therefore, the soundproof wall foundation (25.2%) with 13·16mm steel rebar, the barrier (25.2%), and the precast deck plate (26.4% ~ 27.4%) with 13·16·19mm were different in the total weight ratio, and the total weight of GFRP reinforcement was analyzed to be 77.241kg (26.7%). The total carbon emission of 289,256kg of steel rebar input to the barrier, soundproof wall, and precast floor plate of the target bridge was 775,206kgCO2eq, and if replaced by GFRP rebar, the total carbon emission of 77,241kg was 257,213kgCO2eq, which could reduce the total carbon emission of 517,993kgCO2eq (66.8%).

Carbon emissions emitted at the same standard were analyzed for the transport stage of each material for the production of the final object. The total weight of each material required for manufacture is 289,256kg of steel rebar and 77,241kg of GFRP rebar, which is expected to take about 58 for steel rebar and about 16 carrying vehicles for GFRP rebar. It was analyzed that the carbon emission of 252kgCO2eq (73.3%) can be reduced by 344kgCO2eq of steel rebar and 92kgCO2eq of GFRP rebar in the transport

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stage calculated by applying carbon emission of the carrying truck based on hourly and transport distance. From these results, GFRP is high in the production stage, but since only carbon source unit of the truck according to the total transport weight is applied separately in the transport stage, the weight reduction rate and carbon emission reduction rate are the same. Based on the final object (protection wall, soundproof wall foundation, precast deck plate), the carbon emission effect of 1:1 replacement with total steel reinforcement usage and GFRP rebar was analyzed, and carbon emission could be reduced at a high rate (66.8%) by changing materials in existing steel reinforcement and concrete structures.

Table 2 Calculation of input volume by material for barriers, soundproof walls, and precast decks

		Steel rebar			GFRP rebar		
Barriers	Diameter (mm)		16	13		16	13
	Length(m)		3,675	10,333		3,675	10,333
	Unit weight (kg/m)		1.560	0.995		0.394	0.251
	Weight(kg)		5,733	10,281		1,448	2,594
	Total weight(kg)	**16,014**			**4,042**		
	Rate(%)	**100.0**			**25.2**		
Sound proof wall (foundation)	Diameter (mm)	13			13		
	Length(m)	13,947			13,947		
	Unit weight (kg/m)	0.995			0.251		
	Total weight(kg)	**13,878**			**3,501**		
	Rate(%)	**100.0**			**25.2**		
Precast decks (1)	Diameter (mm)	19	16	13	19	16	13
	Length(m)	29,165	37,054	8,193	29,165	37,054	8,193
	Unit weight (kg/m)	2.250	1.560	0.995	0.619	0.394	0.251
	Weight(kg)	65,621	57,804	8,152	18,053	14,599	2,056
	Total weight(kg)	**131,577**			**34,708**		
	Rate(%)	**100.0**			**26.4**		
Precast decks (2)	Diameter (mm)	19	16	13	19	16	13
	Length(m)	53,582	-	7,263	53,582	-	7,263
	Unit weight (kg/m)	2.250	1.560	0.995	0.619	0.394	0.251
	Weight(kg)	120,560	-	7,227	33,167	-	1,823
	Total weight(kg)	**127,787**			**34,990**		
	Rate(%)	**100.0**			**27.4**		
Total weight (kg)		**289,256**			**77,241**		
Rate (%)		**100.0**			**26.7**		

Next, sensitivity analysis was performed on carbon emission according to the weight ratio of the GFRP reinforcing bar. The total weight of rebar based on the final object is 289,256kg, and the total weight of GFRP reinforcement bars is 77,241kg, so the weight ratio of GFRP reinforcement bars is 0.267 of rebar. Based on the carbon emission source unit of each material applied (2.68kgCO2eq/kg, 3.33kgCO2eq/kg of GFRP reinforcement), the weight ratio of GFRP reinforcement bars exceeding the carbon emission of rebars is 0.805, as shown in Figure 1.

If the carbon emission according to the carbon emission unit of the GFRP rebar is greater than the carbon emission unit of the rebar divided by the weight ratio (0.267) of the GFRP rebar based on the final object, it can be seen that the carbon emission of the GFRP rebar is higher than that of the steel reinforcement as shown in Figure 2.

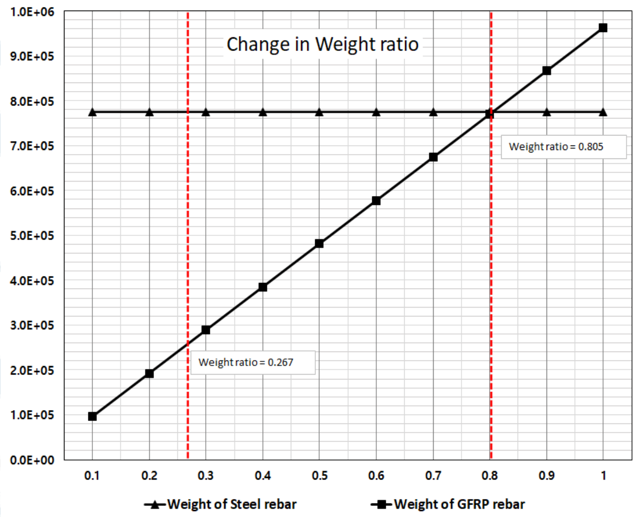

Figure 1. Interval of excess carbon emission of GFRP rebar relative to steel rebars (weight ratio)

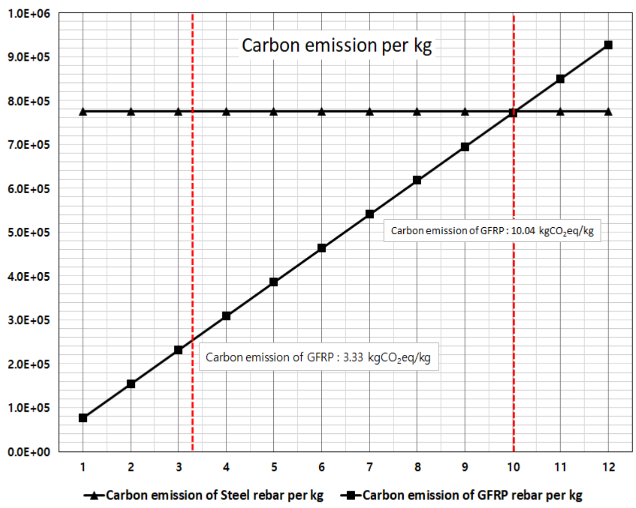

Figure 2. Interval of excess carbon emission of GFRP rebar relative to steel rebars (Carbon emission units)

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IV. SUMMARY AND CONCLUSION

In this study, the possibility of reducing carbon emission of GFRP rebars that can replace steel rebars, which are traditional construction materials, was analyzed. The environmental effect of GFRP rebars was analyzed by comparing the total carbon emission of alternative materials (GFRP rebars) against the existing material (steel rebar) based on the final structure.

As a result of the analysis, the GFRP rebar to the steel rebar was 26.7% of the total weight based on the production of the same final structure, and even though the carbon emission unit of the GFRP rebar was 124.3% higher than that of the steel reinforcement, the carbon emission could be reduced by 66.8%. Therefore, the active application of GFRP rebars in the construction industry is expected to provide environmental benefits such as securing durability of structures and reducing carbon emissions, and additional benefits such as energy use and worker convenience in transportation and on-site installation work due to low unit weight compared to existing materials.

If data that can be compared between the maintenance stage and the disposal stage of the GFRP rebar applied structure is accumulated in the future, a true-life cycle evaluation (LCA) can be achieved. In addition, it is judged that the carbon emission source unit and the LCI DB for each material should be established on the same basis so that intuitive carbon emission comparison can be performed at various construction sites.

V. ACKNOWLEDGMENT

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