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A Comparative Study on the Impact of Global Warming of Applying Low Carbon Factor Concrete Products

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***Abstract*—**Environmental impact assessment techniques have been developed as a result of the worldwide efforts to reduce the environmental impact of global warming. By using the quantification method in the construction industry, it is now possible to manage the greenhouse gas is to systematically evaluate the impact on the environment over the entire construction process. In particular, the proportion of greenhouse gas emissions at the production stage of construction material occupied is high, and efforts are needed in particular in the construction field.

In this research, intended for concrete products for the construction materials, by using the LCA method, we compared the results of environmental impact assessment and carbon emissions of developing products that have been applied low-carbon technologies compared to existing products. As a results, by introducing a raw material of industrial waste, showed carbon reduction. Through a comparison of the carbon emission reduction effect of low carbon technologies, it is intended to provide academic data for the evaluation of greenhouse gases in the construction sector and the development of low carbon technologies of the future.

***Keywords*—**CO_2 Emissions, CO_2 Reduction, Ready-mixed Concrete, Environmental Impact Assessment.

I. Introduction

A. Research Background and Purpose

WORLDWIDE concern about reducing the environmental impact of global warming has led to the development of techniques that quantitatively assess and ameliorate the environmental impact of this phenomenon.

Also, institutional and political efforts to reduce greenhouse gases have been actively made by a lot of countries in the world. In particular, the construction industry is a national key industry in Korea, and accounts for about 48% of total material consumption and 40% of energy consumption [1]. Thus, there is an urgent need to make efforts to reduce the relevant environmental load. The CO_2 emissions occurring in the production stage of construction material account for about 1/4 of emissions in the construction field, and this affects CO_2 emissions from the construction to the demolition stage.

Therefore, this study aims to contribute to the production and development of carbon emission reduction material by selecting concrete material among the major materials of a building and by comparing the reduction in the environmental load after the application of carbon reduction elements with that of existing products.

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B. Research Method and Scope

To assess the environmental impact of construction material, quantitative environmental impact information on products was presented using the life cycle assessment (LCA), which is the Type III environmental labeling assessment method of international standard ISO 14025 [2], [3].

In this study, for concrete products, which are the structural material of a building, especially ready-mixed concrete (hereinafter remicon) products, carbon reduction techniques that had been applied to each product were examined in the system boundary of "cradle to gate (from the collection of raw material to the shipment of products)" depending on the collection, transportation, and production process of the input material; and improvements in carbon emission reduction relative to the reference product of each product were compared using the result values of the environmental impact assessment.

II. Environmental Declaration of Existing Concrete Product

A. Environmental Declaration of Concrete Products in Korea

The carbon labeling system, which is a representative Type III environmental declaration system in Korea, is operated by the Korea Environmental Industry & Technology Institute that is affiliated with the Ministry of Environment. Currently, 165 enterprises, 313 workplaces, and 1,428 products have obtained the certification (as of July 23, 2014) [4].

Certification target products are classified into production goods, non-energy use durable goods, non-durable goods, service, and energy use durable goods. Construction material corresponds to production goods, and thus has the system boundaries of a resource production stage for product production, a primary raw material production stage, and a product manufacturing stage.

In the case of remicon products, a total of two products have obtained the carbon labeling certification [5]. They show different total amounts of carbon depending on the strength of the concrete, but it is thought that they could be used as the reference product of the developed product for the domestic industry.

For the two products in Table I, data were collected by dividing them into a pre-manufacturing stage and a manufacturing stage, and the total emission was estimated by converting the data to greenhouse gas emission using the LCI DB for the input. The result indicated that the emission ratio was 11% for the pre-manufacturing stage, and 89% for the manufacturing stage.

TABLE I
CHARACTERISTICS OF CO_2 LABELLING PRODUCT IN KOREA (UNIT: KG CO_2/M^3)

Division	Product I	Product II
Standard	25-21-150	25-24-150
Pre-manufacturing Phase (Occurrence Rate of GHGs)	21.6 (11%)	21.15 (11%)
Manufacturing Phase (Occurrence Rate of GHGs)	167.66 (89%)	179.74 (89%)
Total Emissions Amount (Occurrence Rate of GHGs)	189 (100%)	201 (100%)

TABLE II
ELEMENTAL TECHNOLOGIES FOR REDUCING CARBON EMISSIONS OF CONSTRUCTION MATERIALS

Life Cycle	$LCCO_2$ Reduction Technology
Production Stage (Raw materials supply and Manufacturing)	Materials Reduction
	Use of Industrial waste materials
	Process Efficiency Improvement
	Fuel Change
	New Materials Application
Transport Stage	Diminishing of Distance
	Fuel-efficiency Improvement
Construction Stage	Construction Method Improvement (Non-curing)
	High efficiency machinery
	Fuel Change
Use Stage	CO_2 Reduction of Using buildings (Reduction of energy consumption)
	Long-life span product(High Strength)
	Maintenance Improvement (Reduction of Input materials)
Disposal Stage	Recyclability Improvement
	etc.

B. Elemental Techniques for the Carbon Emission Reduction of Construction Materials

For the low carbon techniques applied to carbon labeling certification products, the carbon emission reduction from the decrease in the use of Portland cement due to the use of environment-friendly cement accounts for the largest portion, and the efforts for this include the use of recycled resources/industrial by-products and the application of admixture.

Table II summarizes the techniques that can reduce $LCCO_2$ during the life cycle of construction material (i.e., raw material collection, primary product production, transportation, construction, use, and disposal) [6].

In this study, the amounts of carbon emission reduction relative to the reference product of each product depending on the application of low carbon techniques for each product in the production stage of remicon products were estimated and compared.

III. ASSESSMENT TARGET AND ENVIRONMENTAL IMPACT ASSESSMENT

A. Assessment Target Selection

By selecting remicon products, which are the most widely used structural material of a building; the environmental load reduction depending on the application of carbon emission reduction element techniques was compared with that of a reference product.

B. Assessment Method

1. LCA Assessment Plan

The environmental impact assessment technique is performed based on life cycle assessment (LCA), which is used internationally. This is a method that can quantitatively assess potential environmental impact considering the usage of raw material and energy that are used during the life cycle of a product and service and the environmental load for the material emitted to the environments.

LCA is a standard assessment tool for environmental labeling, and provides the basis for evaluation that induces environmental load reduction by quantitatively assessing the impact of a product and service on society and environments in various aspects.

2. Comparative Assessment Plan

The purposes of the comparative assessment of each material are to assess the environmental performance of the material to which new techniques and new materials have been applied compared to existing products, and to suggest the basis for evaluation that can determine the environmental impact for the same performance to users.

TABLE III
CHARACTERISTICS OF EACH PRODUCT

Division	Product A	Product B
End-product	Ready-mixed Concrete	Ready-mixed Concrete
Standard	25-50-600(Slump flow)	25-50-150
Function	To form structural frame of reinforced concrete building	To form structural frame of reinforced concrete building
Functional Unit	50MPa Ready-mixed $1m^3$ Concrete Production	50MPa Ready-mixed 1 m^3 Concrete Production
CO_2 Reduction Technology	Resource recycling (Use of industrial waste)	Recycling Materials 100%
Reference Product	50MPa OPC Concrete	50MPa OPC Concrete
Division	Product A	Product B
End-product	Ready-mixed Concrete	Ready-mixed Concrete
Standard	0.6m×3.0m×0.1m	25-24-150
Function	To form structural frame of reinforced concrete building	To form structural frame of reinforced concrete building
Functional Unit	· Ready-mixed 1 m^3 Concrete Production · Panel 1 Unit Module(46kg)	24MPa Ready-mixed 1 m^3 Concrete
CO_2 Reduction Technology	· Non-cement · Use of Industrial waste materials · Long-life span (High Strength) · Industrial waste Reduction	Recycling Materials 100%
Reference Product	Extruded concrete panel	24MPa OPC Concrete

Therefore, for the assessment of each product, the LCA technique was identically applied. The assessment and comparison were performed considering six aspects of environmental load using the domestic TOTAL program, and the results of the carbon emission ratio in the pre-manufacturing stage and manufacturing stage of construction material were obtained in terms of global warming. The assessment targets were developed remicon products, and the comparison targets were existing products. As it was an assessment of material, only the load in the production stage of construction material was considered without considering construction and maintenance, where the construction material is inputted, constructed, and applied to a building, and the disposal stage of a building.

3. Assumptions and Limitations

LCA is a process that quantifies the flow of the material and energy inputted into a system boundary; and data omission for various inputs and outputs in each manufacturing process stage needs to be prevented, and quantitative data collection needs to be performed. However, a lot of time and efforts are required to examine the flow and process of many inputs during the life cycle of a product. Thus, LCA collects data based on the material that has a cumulative mass contribution of 95%~99% by suggesting 'cut-off criteria.'

Therefore, for the data collected in this study, all the production data were collected in principle; but in the case of the inputs and outputs that cannot be collected for a product in the prototype stage, the cut-off criteria were applied.

In addition, for the assessed products, the power consumption required for the production of concrete products was estimated by assuming the power consumption needed for the production of products with the same performance, assuming that the same process was used.

C. Production Process and System Boundary of Product

1. HVMA High-Strength Remicon (Product A)

It is high-strength concrete that is used for the structure and foundation of a building, bridges, and tunnels. Remicon is produced through a material transportation and batching process and a mixing process.

Fig. 1 and Table IV show the process flowchart that presents the production process of the high-strength remicon depending on the system boundary, and the data collection list for the inputs and outputs for each data category.

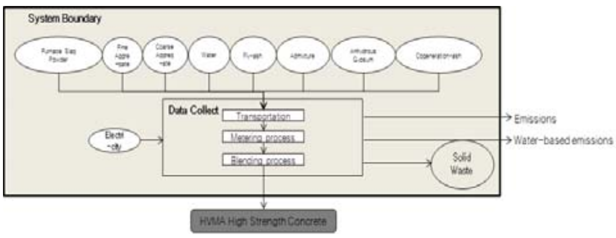

Fig. 1 Process flow chart of HVMA high strength remicon

2. Non-Cement Concrete for PC (Product B)

It is concrete using only blast furnace slag without using cement. The mixing process is performed depending on the mix proportion of input material; and for the inputted energy, only electricity is used.

The system boundary was defined as cradle to gate, which includes stages from the collection of raw material to the transportation of raw material and the remicon manufacturing process excluding the usage stage.

TABLE IV
DATA SOURCE OF PRODUCT A

Division	Parameter	DB Application	DB	Origin	Year
Input	Cement	O	Portland cement	KLCI DB (ME)	2013
	Furnace Slag Powder	X	n/a	n/a	n/a
	Fly-ash	X	n/a	n/a	n/a
	Anhydrous Gypsum	O	Gypsum, mineral, at mine	Foreign DB	2005
	Cogeneration -ash	X	n/a	n/a	n/a
	Coarse Aggregate	O	Gravel (Crushed rock)	Construction Material LCI DB (MLIT)	2008
	Fine Aggregate	O	sand, at mine	Foreign DB	2005
	Admixture	X	n/a	n/a	n/a
	Water	X	Elementary flow	n/a	n/a
	Electricity	O	Electricity	KLCI DB (MKE)	2000
Output	Emission	X	n/a	n/a	n/a
	Water-based emissions	X	n/a	n/a	n/a
	Solid waste	X	n/a	n/a	n/a
Transport	Cement	O	23.1-25ton Truck	Ministry of Environment (ME)	2003
	Furnace Slag Powder	O	23.1-25ton Truck	ME	2003
	Fly-ash	O	23.1-25ton Truck	ME	2003
	Anhydrous Gypsum	O	23.1-25ton Truck	ME	2003
	Cogeneration -ash	O	23.1-25ton Truck	ME	2003
	Coarse Aggregate	O	23.1-25ton Truck	ME	2003
	Fine Aggregate	O	23.1-25ton Truck	ME	2003
	Admixture	O	23.1-25ton Truck	ME	2003

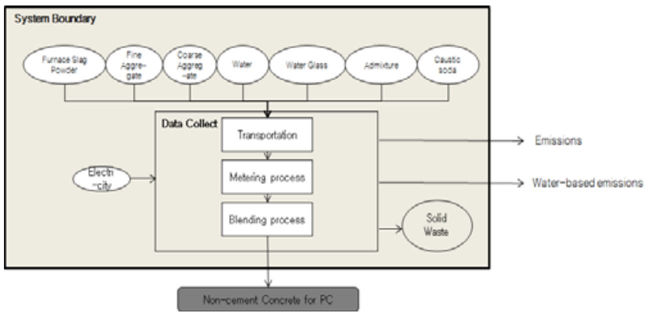

Fig. 2 Process flow chart of non-cement concrete for PC

3. Non-Cement Concrete Panel (Product C)

It is a non-cement light-weight concrete panel that is used as the light-weight wall and interior/exterior material of a building. This product goes through a mixing process through the transportation, mixing, and batching of input material; and the energy inputted in the production process is electricity.

TABLE V
DATA SOURCE OF PRODUCT B

Division	Parameter	DB Application	DB	Origin	Year
Input	Furnace Slag Powder	X	n/a	n/a	n/a
	Coarse Aggregate	O	Gravel (Crushed rock)	Construction Material LCI DB (MLIT)	2008
	Fine Aggregate	O	sand, at mine	Foreign DB	2005
	Water Glass	X	Sodium silicate	KLCI DB (ME)	2003
	NaOH	O	Caustic soda	KLCI DB (ME)	2003
	Water	O	Potable water	KLCI DB (ME)	2013
	Electricity	O	Electricity	KLCI DB (MKE)	2000
Output	Emission	X	n/a	n/a	n/a
	Water-based emissions	X	n/a	n/a	n/a
	Solid waste	X	n/a	n/a	n/a
Transport	Furnace Slag Powder	O	Highway transport	KLCI DB (ME)	2003
	Coarse Aggregate	O	Highway transport	KLCI DB (ME)	2003
	Fine Aggregate	O	Highway transport	KLCI DB (ME)	2003
	Water Glass	O	Highway transport	KLCI DB (ME)	2003
	NaOH	O	Highway transport	KLCI DB (ME)	2003

TABLE VI
DATA SOURCE OF PRODUCT C

Division	Parameter	DB Application	DB	Origin	Year
Input	Bottom Ash (4~10mm)	X	n/a	n/a	n/a
	Bottom Ash (0.1~2mm)	X	n/a	n/a	n/a
	Fly Ash	X	n/a	n/a	n/a
	Furnace Slag	X	n/a	n/a	n/a
	Water Glass	O	Sodium silicate	KLCI DB (ME)	2003
	NaOH	O	Caustic soda	KLCI DB (ME)	2003
	Water	O	Potable water (EDP2013)	KLCI DB (ME)	2013
	Electricity	O	Electricity	KLCI DB (MKE)	2000
	B-C Oil	O	Bunker Fuel Oil C	KLCI DB (MKE)	2006
Output	Emission	X	n/a	n/a	n/a
	Water-based emissions	X	n/a	n/a	n/a
	Solid waste	X	n/a	n/a	n/a
Transport	Bottom Ash (4~10mm)	O	Highway transport	KLCI DB (ME)	2013
	Bottom Ash (0.1~2mm)	O	Highway transport	KLCI DB (ME)	2013
	Fly Ash	O	Highway transport	KLCI DB (ME)	2013
	Furnace Slag	O	Highway transport	KLCI DB (ME)	2013
	Water Glass	O	Highway transport	KLCI DB (ME)	2013
	NaOH	O	Highway transport	KLCI DB (ME)	2013

The system boundary was defined as cradle to gate, which includes stages from the collection of raw material to the transportation of raw material and the remicon manufacturing process excluding the usage stage.

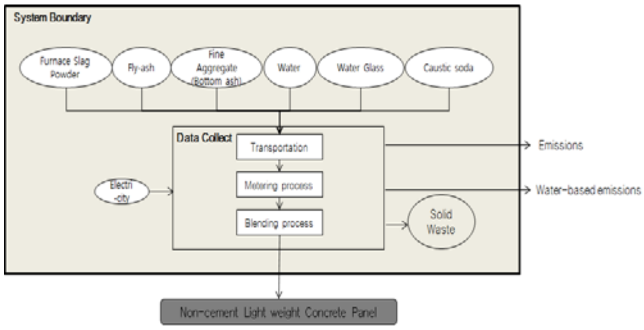

Fig. 3 Process flow chart of non-cement light-weight concrete panel

4. Amorphous Steel Fiber Reinforced Concrete (Product D)

The production process is the same as that of general remicon.

The system boundary was defined as cradle to gate, which includes stages from the collection of raw material to the transportation of raw material and the remicon manufacturing process excluding the usage stage.

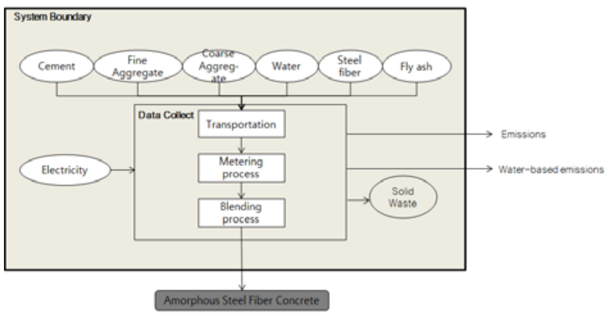

Fig. 4 Process flow chart of amorphous steel fiber concrete

D. Life Cycle Carbon Emission Reduction Elements for Each Material

The carbon emission reduction elements for each construction material whose data had been collected in this study were outlined and summarized in Table VIII.

1. HVMA High-Strength Remicon (Product A)

It is a developed product that goes through the same production process as that of remicon with the same performance. However, direct emission from cement usage is reduced by using recycled resources in the production stage, long life is enabled by the high strength in the usage stage, and indirect carbon emission is reduced by the improvement in the recycling rate in the disposal stage of the product.

2. Non-Cement Concrete for PC (Product B)

It is a product that reduces carbon emission by decreasing the usage of cement using only blast furnace slag (i.e., industrial byproduct) without using cement during product production in the production stage. Thus, the environmental load from cement is significantly reduced due to the decrease in the usage of the raw material of cement.

TABLE VII
DATA SOURCE OF PRODUCT D

Division	Parameter	DB Application	DB	Origin	Year
Input	Cement	O	Portland cement	KLCI DB (ME)	2013
	Coarse Aggregate	O	Gravel (Crushed rock)	Construction Material LCI DB (MLIT)	2008
	Fine Aggregate	O	sand, at mine	Foreign DB	2005
	Fly Ash	X	n/a	n/a	n/a
	Amorphous Steel fiber	○	materials offer	participation company	2014
	Water	X	Elementary flow	n/a	n/a
	Electricity	O	Electricity	KLCI DB (MKE)	2000
Output	Emission	X	n/a	n/a	n/a
	Water-based emissions	X	n/a	n/a	n/a
	Solid waste	X	n/a	n/a	n/a
Transport	Cement	O	Highway transport	KLCI DB (ME)	2013
	Coarse Aggregate	O	Highway transport	KLCI DB (ME)	2013
	Fine Aggregate	O	Highway transport	KLCI DB (ME)	2013
	Fly Ash	O	Highway transport	KLCI DB (ME)	2013
	Amorphous Steel fiber	O	Highway transport	KLCI DB (ME)	2013

TABLE VIII
APPLIED CO_2 REDUCTION TECHNOLOGY TO EACH PRODUCT

$LCCO_2$ Reduction Technology	PRODUCT APPLICATION			
	A	B	C	D
Materials Reduction	O	O	O	-
Use of Industrial waste materials	O	O	O	-
Process Efficiency Improvement	-	-	-	-
Fuel Change	-	-	-	-
New Materials Application	-	-	-	O

3. Non-Cement Light-Weight Concrete Panel (Product C)

It is a product that is manufactured using industrial byproduct for all the inputs in the production stage without using cement. It is a non-cement concrete product that obtains required mechanical strength through alkali activation reaction using recycled aggregate and non-sintered industrial byproduct.

4. Amorphous Steel Fiber Reinforced Concrete (Product D)

During the manufacture of amorphous steel fiber, which is a key input material, energy and carbon reduction can be expected due to process reduction. The environmental load from wire mesh production is reduced because placing is enabled without using wire mesh that is used for the placing of general concrete.

During the manufacture of amorphous steel fiber, which is a key input material, energy and carbon reduction effect is expected due to process reduction. The potential reduction in the usage of additionally inputted material due to the increase in the endurance period during the usage stage (life of a building) is the carbon reduction core technique.

E. Assessment Results of the Carbon Emission for Each Product

The environmental performance of each material was assessed using the TOTAL program based on the Environmental Declaration of Products (Type III) methodology of Korea. After obtaining the assessment results, the environmental impact of the developed products in the pre-manufacturing stage and the manufacturing stage was analyzed in terms of global warming.

1. HVMA High-Strength Remicon (Product A)

The global warming effect that occurs during the production of 1m^3 of HVMA high-strength remicon was 70.19 kgCO_2-eq. The CO_2 emission occurring during the raw material collection in the pre-manufacturing stage accounted for 70.1% of the total emission, and the emission from the use of electricity in the manufacturing stage was 29.9%.

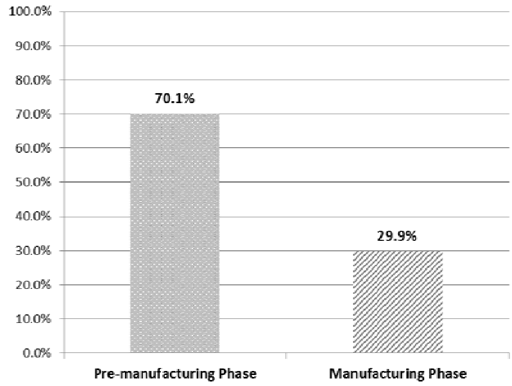

Fig. 5 Proportion of the CO_2 emissions of product A

2. Non-Cement Concrete for PC (Product B)

The global warming effect that occurs during the production of 1m^3 of non-cement concrete for PC members was 147.5kg CO_2-eq. 87.5% of the total greenhouse gas emission for the product production occurred in the pre-manufacturing stage, and 12.5% occurred in the manufacturing stage.

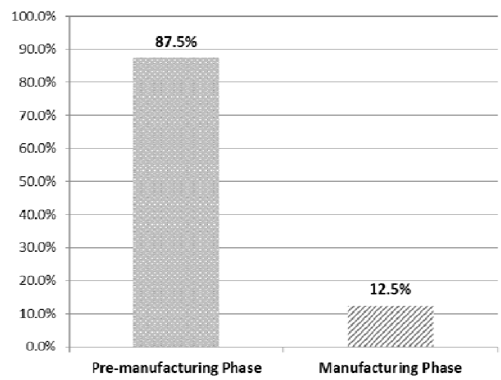

Fig. 6 Proportion of the CO_2 emissions of product B

3. Non-Cement Light-Weight Concrete Panel (Product C)

The global warming effect that occurs during the remicon production for the production of one non-cement light-weight concrete panel module (46 kg) was 187.8kg CO_2-eq. Among them, 69.4% occurred in the pre-manufacturing stage, and 30.4% was the CO_2 emission from the use of electricity in the manufacturing stage.

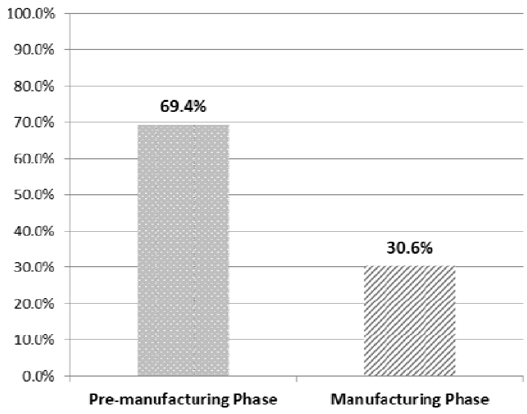

Fig. 7 Proportion of the CO_2 emissions of product C

4. Amorphous Steel Fiber Reinforced Concrete (Product D)

The carbon emission that occurs during the production of 1m^3 of amorphous steel fiber reinforced concrete was 243.4kg CO_2-eq./1m^3. 225.6kg CO_2-eq./1m^3 (94.5%) was emitted in the pre-manufacturing stage for raw material collection, and 17.8 kg CO_2-eq./1m^3 (5.5%) was emitted in the manufacturing stage due to the operation of production facilities by the use of electricity.

TABLE IX
THE RESULT OF ENVIRONMENTAL IMPACTS ON PRODUCT A VS. BASELINE PRODUCT

Division	Product A	Baseline Product
Pre-manufacturing Phase	64	352
(Occurrence Rate of GHGs)	(70.1%)	(93.9%)
Manufacturing Phase	27	23
(Occurrence Rate of GHGs)	(29.9%)	(6.1%)
Total Emissions Amount	91	375
(Occurrence Rate of GHGs))	(100%)	(100%)

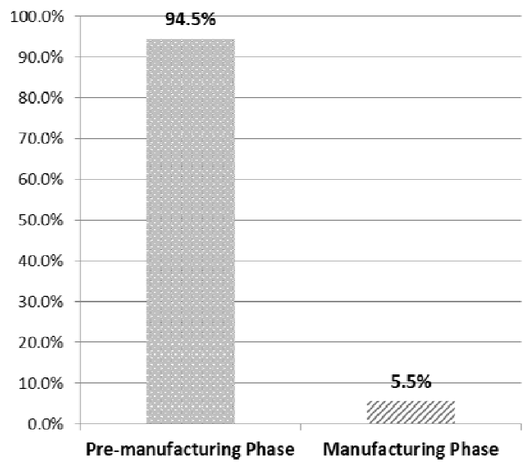

Fig. 8 Proportion of the CO_2 emissions of product D

TABLE X
THE RESULT OF ENVIRONMENTAL IMPACTS ON PRODUCT B VS. BASELINE PRODUCT

Division	Product B	Baseline Product
Pre-manufacturing Phase	131	527
(Occurrence Rate of GHGs)	(87.5%)	(97.7%)
Manufacturing Phase	19	12
(Occurrence Rate of GHGs)	(12.5%)	(2.3%)
Total Emissions Amount	150	539
(Occurrence Rate of GHGs))	(100%)	(100%)

IV. COMPARISON OF THE ASSESSMENT RESULTS OF THE DEVELOPED MATERIALS RELATIVE TO THE REFERENCE PRODUCTS

A. HVMA High-Strength Remicon (Product A)

The element technique used for the carbon emission reduction of Product A was the improved input ratio of recycled resource raw material compared to that of the reference product. The recycled resource raw material input ratio of the developed product was 21.9%, and that of the reference product was 6.8%.

For the carbon emissions of the developed product and the reference product in the production stage, the carbon emission decreased to about 1/5 of the original value when the recycled resource raw material mixing ratio was increased by about three times.

B. Non-Cement Concrete for PC (Product B)

For Product B, direct emission from the use of cement is excluded by using recycled resources for the input material, and indirect carbon emission is expected to decrease through the use of recycled resources, the increased longevity due to the high strength, and the improved recycling rate in the disposal stage.

The recycled resource raw material input ratios of the developed product and the reference product were 15.7% and 0%, respectively.

TABLE XI
THE RESULT OF ENVIRONMENTAL IMPACTS ON PRODUCT C VS. BASELINE PRODUCT

Division	Product C	Baseline Product
Pre-manufacturing Phase	134	355
(Occurrence Rate of GHGs)	(69.4%)	(87.7%)
Manufacturing Phase	59	50
(Occurrence Rate of GHGs)	(30.6%)	(12.3%)
Total Emissions Amount	193	405
(Occurrence Rate of GHGs))	(100%)	(100%)

In the production stage, when the recycled resource of the developed product was used as cement substituting raw material, the carbon emission of the production stage decreased by about 73% since there was no environmental impact from cement.

C. Non-Cement Light-Weight Concrete Panel (Product C)

The data collection for the existing product was conducted based on existing research literature [4]. Product C has the same production process as that of the reference product. However, direct emission from the use of cement is excluded by using recycled resources for the raw input material, and indirect carbon emission is expected to decrease through the use of recycled resources and the improved recycling rate in the disposal stage.

TABLE XII
THE RESULT OF ENVIRONMENTAL IMPACTS ON PRODUCT D VS. BASELINE PRODUCT

Division	Product D	Baseline Product
Pre-manufacturing Phase	225.6	302.4
(Occurrence Rate of GHGs)	(94.5%)	(94.5%)
Manufacturing Phase	17.8	17.7
(Occurrence Rate of GHGs)	(5.5%)	(5.5%)
Total Emissions Amount	243.4	320.1
(Occurrence Rate of GHGs))	(100%)	(100%)

The recycled resource raw material input ratios of the developed product and the reference product were 83.8% and 4.6%, respectively.

In the pre-manufacturing stage, when the recycled resource of the developed product was used as cement substituting raw material, the carbon emission in the pre-manufacturing stage (raw material collection) decreased by about 54% when the recycled resource input ratio was increased by about 20 times.

D. Amorphous Steel Fiber Reinforced Concrete (Product D)

For Product D, the data collection for the reference product was conducted based on the same method, and the remicon specification and production process were identical.

The carbon emission during the production of Product D (1 m^3) was 243.4 kg CO_2-eq., which was about 25% smaller than that during the production of general concrete (320.1 kg CO_2-eq.). It is thought that this reduction is brought about because direct emission from the use of cement was excluded by using recycled resources for the input material.

V. CONCLUSION

To compare the carbon emission of remicon products, which are the most important material among the structural materials of a building, depending on the application of carbon reduction element techniques, with the carbon emissions of generally used reference products, the carbon emissions were assessed using the same assessment technique. The results indicated that there was a distinct difference in terms of global warming (carbon emission), and the results of the comparative assessment of each material can be summarized as follows.

In the case of HVMA high-strength concrete, the recycled resource input ratio was 21.9%, which was about three times higher than that of the reference product (6.8%). In this regard, the carbon emission decreased to about 1/5 of the original value in terms of its contribution to global warming. For the power consumption in the production process, the same process was used, and there was no carbon emission change relevant to this.

The non-cement concrete for PC members had recycled resource input ratio of 15.7%, and the reference product had no recycled resource input. When cement substituting industrial byproduct (ground granulated blast furnace slag) was used among the inputs of the target product, the carbon emission from the raw material collection in the pre-manufacturing stage decreased by about 73% since there was no environmental impact from cement production.

In the case of the non-cement light-weight concrete panel, the recycled resource raw material input ratio of the target product was 83.8%, and that of the reference product was 4.6%. When cement substituting raw material was used, the carbon emission decreased by about 54% when the recycled resource input ratio in the production process was increased by about 20 times.

In the case of the amorphous steel fiber reinforced concrete, the results of the carbon emission assessment depending on the recycled resource input ratio are thought to be insignificant, and thus cannot be compared. The environmental impacts due to the change in the input material (new material), which is the characteristic of this product, were compared.

The carbon emission during the production of 1m^3 of amorphous steel fiber reinforced concrete was 243.4kg CO_2-eq., which was about 25% smaller than that during the production of general concrete (320.1 kg CO_2-eq.).

In this regard, it was estimated and compared as the amount of wire mesh needed for the placing of general concrete. There was almost no difference in the input and carbon emission of steel fiber (3.301kg CO_2-eq.) and wire mesh (3.23 kg CO_2-eq.).

It is thought that the difference in the carbon emissions between the developed product and the reference product was due to the reduction in cement usage as steel fiber was used in the manufacturing process.

As described above, the reduction in the environmental load due to the input of recycled resources during product production and the use of industrial byproducts as recycling input material had large effects on the reduction of the environmental impact occurring in the life cycle of the product production.

These research data could be used as basic data in the material development field for reducing the consumption of resources through the recycling of industrial byproducts and for developing new materials.

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