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Mechanical Properties of Carbon Fiber Reinforced Porous Concrete for Planting

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Abstract

The mechanical properties of fiber reinforced porous concrete for use as a planting material were investigated in this study. Changes in physical and mechanical properties, subsequent to the addition of carbon fiber and silica fume, were studied. The effects of recycled aggregate were also evaluated. The applicability as planting work concrete material was also assessed. The results showed that there were no remarkable changes in the void and strength characteristics following the increase in proportion of recycled aggregate. Also, the mixture with 10% silica fume was found to be the most effective for strength enforcement. The highest flexural strength was obtained when the carbon fiber was added with 3%. It was also noticed that PAN-derived carbon fiber was superior to Pitch-derived ones in view of strength. The evaluation of its usage for vegetation showed that the growth of plants was directly affected by the existence of covering soil, in case of having the similar size of aggregate and void.

Keywords: porous concrete, carbon fiber, recycled aggregate, silica-fume, flexural strength

1. Introduction

Industrialization has made Korea enjoy abundance in living, but in contrast, the destruction of the environment and uncontrolled exploitation of natural resources has exhausted resources with economic considerations replacing environmental ones. In consequence to this development, the developed areas have been seriously contaminated destructing the eco-system in those areas. At the United Nations Conference on the Environment and Development in 1992, it was advocated that the combination of environmental concerns together with development is more desirable than mere conservation. The Rio Declaration and Agenda 21 were adopted, which in principle pursue the development of environmentally sound transactions for environmental protection. In addition, research and development of new concepts and technologies have more substantially taken into consideration the environment. Consequently, in the construction sector, development is being made considering both environmental problems and improving scenic beauty of cities.[1)] The harmony between nature and concrete structures was also required. In view of this requirement, various research paths are being taken focusing on coarse aggregates to make multi-functional porous concrete2) having continuous voids so as to improve water and air permeability,[3-4)] acoustic absorption, water purification, and applicability to vegetation.[5-8)] Therefore, in this study, the physical and mechanical properties of porous concrete were investigated with regard to their strength increase and the applicability of recycled aggregate when carbon fiber and silica fume were used in the mixture. The effect of the proportion of added recycled aggregate and the applicability of the porous concrete as a planting material was evaluated.

2. Experimental work

2.1 Conditions and variables

The void of the porous concrete is dependent on the purposes and places of its use. For instance, as water permeable concrete[9)] for road paving and retain walls are required to have certain water permeability and high strength, it have

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been made to have low void while that for vegetation and water purification is required to have higher void.[5] The strength of the porous concrete is affected by the void and the binder surrounding the aggregates.[4] In increasing the strength of the binder, it is effective to lower the mixing ratio of water and binder to around 25%□30%, and the flow value of cement paste should be adjusted adequately by its production method. Therefore, in this study, in order to make high performance porous concrete that can be used for vegetation as shown in Table 1, parameters were set as W/B=25%, Flow value=210mm, and theoretical void ratio= 25%. Also, two types of carbon fiber were mixed applying their mixing ratio of 1%, 3%, 5%. Silica fume was added at mixing ratio 5, 10 and 20%. To comprehend the applicability of recycled aggregates, two mixing ratios of 50% and 100% were applied. And the physical and mechanical properties such as void ratio, water permeability, unit weight, compressive strength, flexural strength and flexural toughness, etc. were measured. The growth of plant on the porous concrete was also evaluated to assess its applicability as a planting material.

2.2 Materials

Ordinary portland cement manufactured by a Korea company, was selected for this research. Maximum 20mm crushed stones and recycled aggregate supplied by "H" company in Keumsan, Chungnam were used for this research. Their physical properties are shown in Table 2.

Ultra-fine powdered Silica fume supplied by Elkem Co, Australia was used. The chemical and physical properties of the material are shown in Table 3.

PAN and Pitch derived carbon fibers supplied by Kosaka Co. in Japan were employed. The physical characteristics of the material are shown in Table 4.

The highly polymerized naphthalene sulphonate,(Table 5) from a "K" company in Japan was used for the test. This is a type of water reducing agent which improves the properties of concrete through the surface-active action of that.

2.3 Test method

The purpose of the flow test was to ensure adequate fluidity in the production of porous concrete. In this test, the optimum quantity of superplasticizer based on mixing ratio of silica fume was determined in accordance with KS L 5111.[10)]

The void test of the porous concrete was performed in accordance with the "Test Methods for the void in Porous Concrete" [2)] The weight (W_1) of the cylindrical specimens with its surface in dry state was measured. Then, the weight (W_2) of specimens was fully filled with water by pouring water into the test piece at the top after sealing its bottom

Table 1 Conditions & variables of experiment

Conditions		Variables	
W/B(%)	P/G(%)	25	40
Target void ratio(%)		25	
Target flow(mm)		210	
Contents of carbon fiber(%)		0.1, 0.3, 0.5	
Contents of recycled aggregate(%)		0, 50, 100	
Contents of silica fume(%)		0, 5, 10, 20	
Test Items	Cement paste	Flow(㎜)	
	Porous Concrete	Void ratio(%) Coefficient of permeability (cm/sec) Unit weight(kg/m^3) Compressive strength(MPa) Flexural strength(MPa) Flexural toughness(MPa) Estimate planting	

Table 2 Physical properties of aggregates

Items	Gradation (mm)	Specific gravity	Unit weight (kg/m^3)
Crushed aggregate	10~20	2.69	1,489
Recycled aggregate	10~20	2.34	1,336

Items	Water absorption (%)	Absolute volume (%)
Crushed aggregate	0.70	55.4
Recycled aggregate	1.32	57.1

Table 3 Proporties of silica fume

Chemical composition (%)							
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	SO_3	lg.loss
65.3	25.5	4.25	1.2	0.98	0.21	1.03	3.63

Physical properties		
Specitic gravity	Blain's (㎡/g)	Particle Size (㎛)
2.1	3,124	420

Table 4 Proporties of carbon fiber

Type / Properties	PAN derived carbon fiber	Pitch derived carbon fiber
Length (mm)	6.0	6.0
Diameter(㎛)	6.8	14.5
Specific gravity	1.78	1.63
Young's modulus (MPa)	225,400	37,240
Tensile strength (MPa)	3428	764
Elongation(%)	1.6	2.1

and sides. The difference between W_1 and W_2 was divided by the volume $[V_1]$ of the test specimen to get the value [A] as shown in the following calculation (Eq. 1).

$$A(\%) = (1 - \frac{W_2 - W_1}{V1}) \times 100 \qquad (1)$$

The coefficient of permeability (Eq. 2) was measured in accordance with the "Measurement Method of Permeability Coefficient of Porous Concrete".[2)]

$$K = \frac{L}{H} \times \frac{Q}{A(T_2 - T_1)} \qquad (2)$$

where, K : permeability coefficient :(cm/sec)
L : height of specimens(cm),
H : difference of water head(cm)
A : cross section of specimens(cm^2)
T_2-T_1 : measuring time(sec)
Q : flux from T_1 to T_2(cm^3)

The unit weight of porous concrete was measured in accordance with KS F 2409[11)] for the specimens. This was calculated using the following formula (Eq. 3).

Table 5 Proporties of superplasticizer

Composition	Color	Specific gravity	pH	Content of solid (%)
polymerized naphthalene sulphonate	Dark brown	1.20	7~9	41~45

$$U_W = \frac{W}{V} \qquad (3)$$

where, U_w : unit weight(kg/m^3)
W : weight of specimens(kg)
V : volume of specimens(m^3)

The compressive strength was measured in accordance with the KS F 2405[12)] after 28 curing days. The flexural strength and flexural toughness were measured by the B type Autograph manufactured by S company in Japan in accordance with the KCI-SF-104.[13)]

For evaluation of planting, a 40×40×10cm plate shaped specimens was made and neutralized using a neutralization accelerator to reduce the alkalinity which affects plant growth. Furthermore, this plate was filled with the filling material for water retentive made from a slurry state mixture of garden soil, peat moss, organic fertilizer and water. The ratio of void filling by the filling material for water retentive was set to fill 70% of the void. And the thin soil covering of 3cm thickness was made with a mixture of garden soil, peat moss, organic fertilizer and water. The applicability of the porous concrete to the vegetation was evaluated by sowing herbaceous perennial ryegrass in it depending on the existence or non-existence of soil covering.

2.4 Mix proportions and mixing

The mix proportion in Table 6 was applied in making high performance porous concrete for vegetation in order to comprehend the applicability of recycled aggregate. Varied

Table 6 Mix proportion of porous concrete

Mix series	W/B (%)	P/G (%)	CF/C (wt.%)	SF/(C+SF) (wt.%)	Unit weight(kg/m^3)					
					C	W	G	SF	CF	Admixture
Plain	25	40	-	-	375	94	1444	-	-	1.1
RA-50			-	-	376	94	1335	-	-	1.1
RA-100			-	-	375	94	1256	-	-	1.1
SF-5			-	5	356	94	1444	19	-	1.5
SF-10			-	10	337	94	1444	38	-	1.9
SF-20			-	20	300	94	1444	75	-	2.6
PAN-1			1	-	375	94	1444	-	4	1.1
PAN-3			3	-	375	94	1444	-	11	1.1
PAN-5			5	-	375	94	1444	-	19	1.1
Pitch-1			1	-	375	94	1444	-	4	1.1
Pitch-3			3	-	375	94	1444	-	11	1.1
Pitch-5			5	-	375	92	1444	-	19	1.1
RA-50+SF-10			-	10	338	94	1335	38	-	1.9
RA-100+SF-10			-	10	337	94	1256	38	-	1.9
SF-10+PAN-3			3	10	337	94	1444	38	11	1.9
SF-10+Pitch-3			3	10	337	94	1444	38	11	1.9

mixing ratio of recycled aggregate, silica fume, PAN and pitch derived carbon fibers to the aggregate in a single particle size of 10~20 mm, were applied as follows: 50% and 100% for the recycled aggregate; 5%, 10% and 20% for the silica fume; and 1%, 3% and 5% for the carbon fiber. Mixing was done by PAN type forced mixer at a 50 liter capacity. Dry mixing of aggregate, binding material and carbon fiber was done for 30 seconds after feeding them into the mixer in such order, and then further mixing was carried out for one and half minutes after adding water and admixture.

The specimens were made conforming to the "Production of specimens of Porous Concrete" published by ECO Concrete Research Committee in Japan.[2] When mixing was finished, the porous concrete was filled into each mold by applying 25 times of hand tamping each time the mold was filled up to one third its height. After 24 hours of air drying, the mold was removed and the concrete was kept in water of 20±3℃ for standard curing until it reached the required ages.

3. Results and discussion

3.1 Flow

Since the porous concrete has continuous void and aggregates are connected at their contacting points, cement paste should have adequate fluidity in order to maintain continuous void. If the flow value of the cement paste is excessively high, the paste permeates into the void decreasing the number of continuous void. On the other hand, when the flow value is low, the cement paste can hardly be mixed with aggregates decreasing the coating ratio of the aggregate. Therefore, flow values were measured according to the mixing ratio of silica fume to find an optimum fluidity. The measurement results are shown in Fig. 1. It was observed that with the increase of the mixing ratio of silica fume the fluidity decreased requiring the addition of a mixing agent. The quantity of superplasticizer that satisfied the target flow value of 210mm was found to be, by weight ratio, 0.5%, 0.75%, 1.2% and 2.4% respectively for the mixing ratio of silica fume of 0%, 5%, 10% and 20%, respectively.

3.2 Void ratio

When the void in porous concrete is small, the strength of the concrete is relatively high, and plants do not grow well in it. When porous concrete is used for vegetation, the void and the size of the pore are crucial factors directly affecting the growth of roots of the plants.

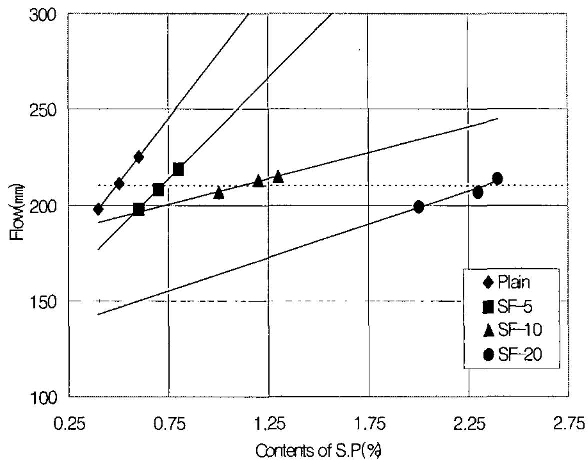

Fig. 1 Flow test

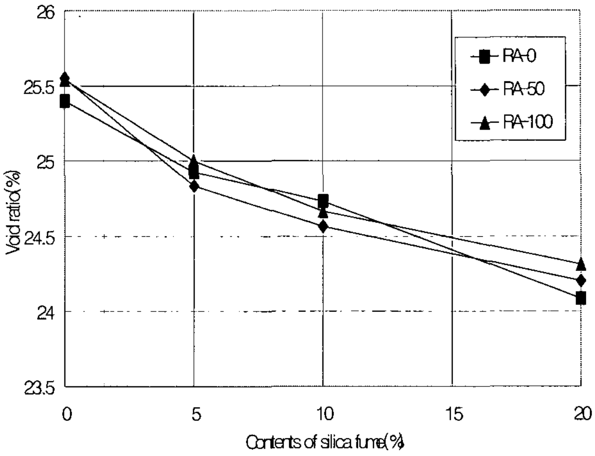

Fig.2 Void ratio by silica-fume

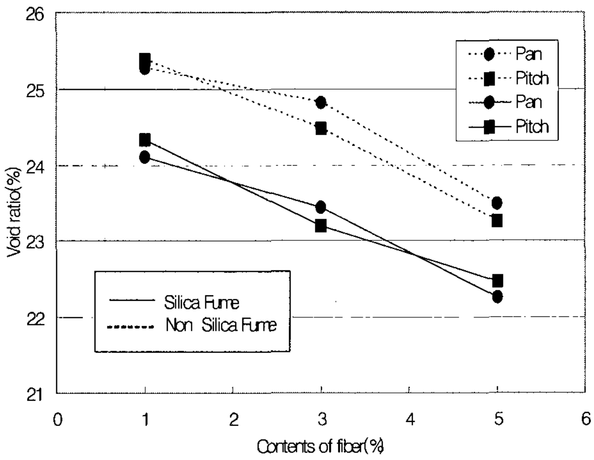

Fig.3 Void ratio by fiber

Fig. 2 shows the result of a measurement of void ratio by mixing ratios of recycled aggregate and silica fume. For each ratio of 0%, 50% and 100% of the recycled aggregate, accordingly as the mixing ratio silica fume increased by 5% 10% and 20%, the void ratio decreased by 1.8%~5.2%, 2.7%~5.3%, 2.1%~4.8% respectively. This is because, with the increase of silica fume, the cement paste volume increased due to the difference in their specific gravity decreasing the number of void made between aggregates.

Fig. 3 shows the change in void ratio versus the mixing ratios of the carbon fiber and whether or not the silica fume was mixed in. With the increase of mixing ratio of carbon fiber by 1%, 3% and 5%, the void ratio of the concrete containing 10% of silica fume and one not containing silica fume decreased by 4.2%~12.3% and 0.03%~8.4% respectively compared to the porous concrete containing no fiber. It is understood from this result that the void decreased because the carbon fibers were filled into the void form by the aggregates as the mixing ratio of carbon fiber increased.

3.3 Coefficient of permeability

Fig. 4 and Fig. 5 show the test results of coefficient of permeability by the mixing ratio of the recycled aggregate, silica fume and carbon fiber. The coefficient of permeability for each mixing ratio of the recycled aggregate, 0%, 50%, and 100% decreased by 9.3%~20.5%, 6.7%~19.5%, 11.6%~20.9% accordingly as the mixing ratio of silica fume increased by 5%, 10% and 20%. It is believed that the coefficient of permeability decreased because the cement paste volume had increased ; due to the specific gravity difference caused by the increase in the mixing ratio of the silica fume. Fig. 5 shows the result of the permeability test versus the mixing ratio of the fiber and the existence of silica fume. Regardless of the type of carbon fiber, the increase in the mixing ratio of the carbon fiber caused a decrease in the permeability. When the silica fume was added, the permeability decreased further. It can be said that the increase in the mixing ratio of the carbon fiber caused the decrease in the void, and accordingly, a decrease in the permeability.

3.4 Unit weight

The test for the unit weight is shown in Fig. 6 and Fig.7 by the mixing ratio of the recycled aggregate, silica fume

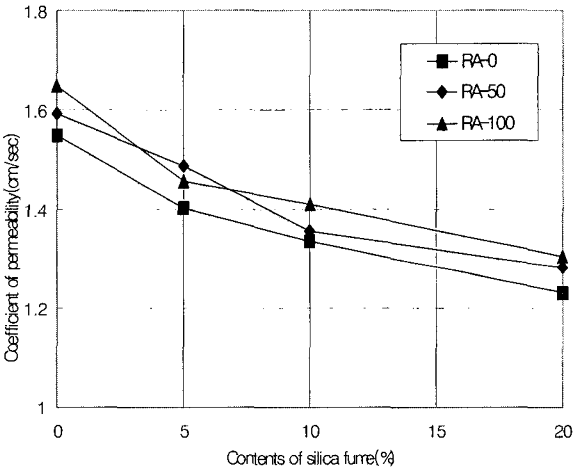

Fig. 4 Coefficient of permeability by silica-fume

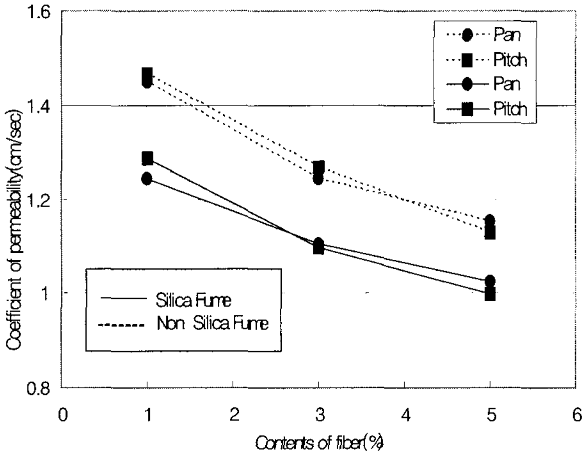

Fig. 5 Coefficient of permeability by fiber

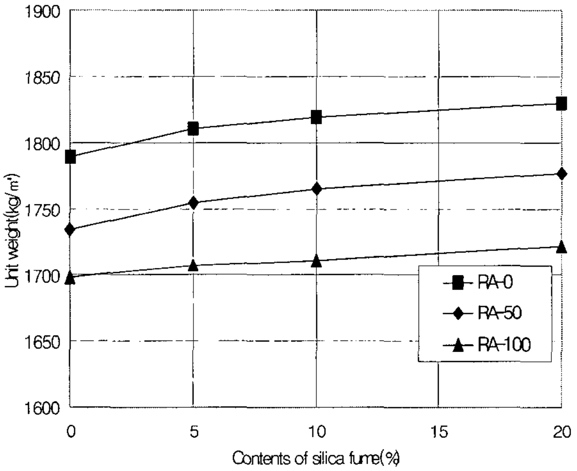

Fig. 6 Unit weight by silica-fume

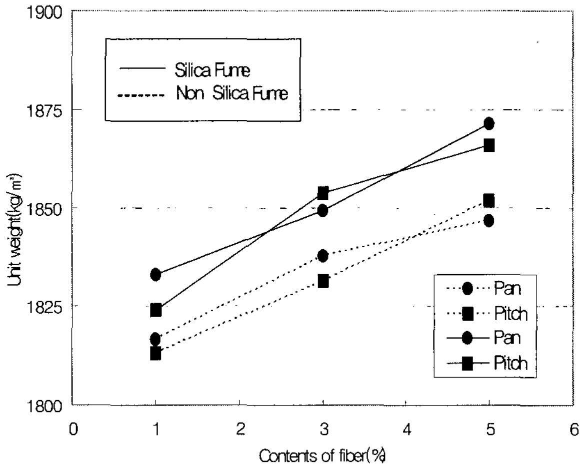

Fig. 7 Unit weight by fiber

and carbon fiber. Fig, 6 indicates the measurement of unit weight for each mixing ratio of the recycled aggregate and silica fume. When the silica fume was not added, unit weight decreased as the mixing ratio of the recycled aggregate increased. It is believed that this is caused by the weight difference between the recycled aggregate and crushed stone. And, as the mixing ratio of the silica fume increased, the unit weight of the recycled aggregate also slightly increased. Fig. 7 shows result of unit weight versus the mixing ratio of the silica fume and carbon fiber. Regardless of the type of carbon fiber, it was observed that the increase in the carbon fiber caused the increase in the unit weight, and a remarkable increase was noticed when the silica fume was added by 10%. This indicates that unit weight increased because the void of the specimen were filled up by the carbon fiber as its mixing ratio increased.

3.5 Properties of strength

Fig. 8 and Fig. 9 show the test result of the compressive strength and flexural strength depending on the changes in the mixing ratio of the recycled aggregate and silica fume. It was observed that against the increase of recycled aggregate, the strength of the concrete decreased. It is believed that the binding force of the cement paste was weakened due to the old pastes attached to the recycled aggregates. For each mixing ratio of the recycled aggregate(0%, 50% and 100%), as the mixing ratio of the silica fume increased by 5%, 10%, and 20%, and the compressive strength increased by 7.1%~20.0%, 6.7%~13.6% and 7.0%~17.3% respectively, while the flexural strength increased by 6.7%~33.9%, 1.8%~17.9 and 1.4%~18.2%. Such increase in strength can be explained that the Pozzolan reaction took place at an early stage between the micro silica fume powder and $Ca(OH)_2$ in the cement, and the $Ca(OH)_2$ formed gel layer between the cement particles increased the strength of the cement paste and the concrete strength. Also, the mixing ratio of 10% silica fume was most effective for better strength. Fig. 10 and Fig. 11 show the test results for the compressive strength and flexural strength according to the change in the

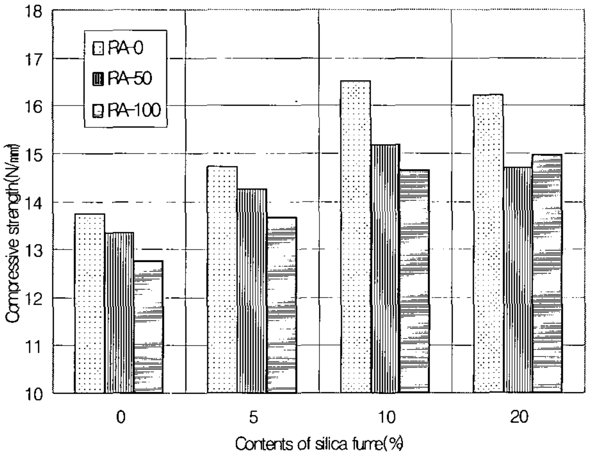

Fig. 8 Compressive strength by silica-fume

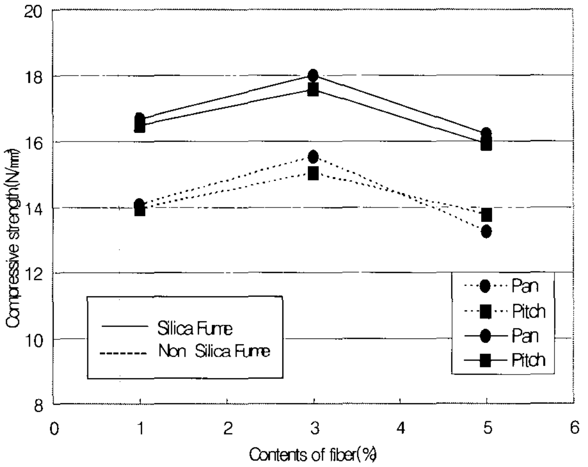

Fig. 10 Compressive strength by fiber

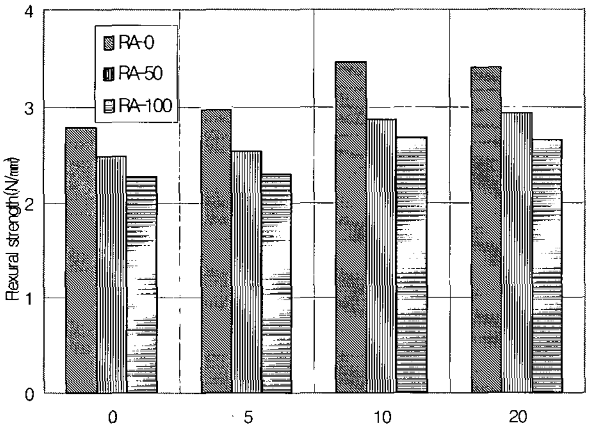

Fig. 9 Flexural strength by silica-fume

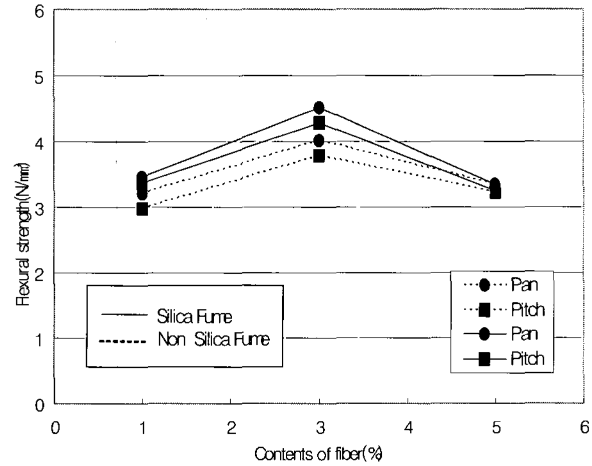

Fig. 11 Flexural strength by fiber

mixing ratio of the carbon fiber and the existence of silica fume. Following the increase of the mixing ratio of the carbon fiber up to 3%, the concrete strength also increased. This can be interpreted that the concrete strength increased as void in the concrete were filled up by the carbon fibers. On the other hand, at its mixing ratio of 5%, the concrete strength decreased, and this can be explained that owing to the excessive mixing of fibers, they were not fully dispersed throughout the cement paste and formed fiber balls, reducing the binding force between the paste and aggregate. In addition, there was slight difference in the concrete strength depending on the types of fiber used.

Concrete containing the PAN derived fiber had slightly higher strength than the concrete containing the Pitch derived one. It can be said that the PAN derived fiber has higher elasticity and strength than the Pitch derived one and also has smaller fiber diameter than the Pitch derived one, making the relative surface area and the aspect ratio(L/D) larger and higher and allowing the fibers to disperse well. The strength characteristics were tested depending on the existence of silica fume for the mixing ratio of carbon fiber. In this test, the specimens having silica fume showed higher strength. The reason for this are that the fine particles of silica fume, by being trapped into the void of the carbon fiber, allowed the carbon fiber to disperse sufficiently, thus enhancing the combining force between carbon fiber and cement particles.

Fig. 12 and Fig. 13 show the load-displacement curves by the mixing ratio of PAN and Pitch derived fibers. It can be observed that the porous concrete's inferior resistance to the deformation improved when the carbon fibers were added. The flexural toughness by the mixing ratio of two types of the carbon fibers were evaluated in accordance with KCI-SF-104. The result showed that the concrete containing those fibers had a higher index of flexural toughness than normal porous concrete. In general, concrete reinforced with PAN derived carbon fibers had higher index of flexural toughness than concrete reinforced with Pitch derived ones. For each case of adding the PAN derived carbon fiber and Pitch derived carbon fiber, the index of flexural toughness increased by 16.7 to 23.5 times and 11.8 to 17.0 times respectively as high as that of normal porous concrete.

In particular, the highest value was obtained when the mixing ratio of carbon fiber was 3%. Concrete containing silica fume had a higher index of flexural toughness than the concrete without silica fume. Therefore, it is understood that carbon fiber is effective for the improvement of the resistance to the deformation.

3.6 Evaluation of applicability for planting

To evaluate the growth state of grass by mix proportion depending on the existence and non-existence of soil covering, its growth was examined for three months from its sprouting. The result was shown in Fig. 14. It was found

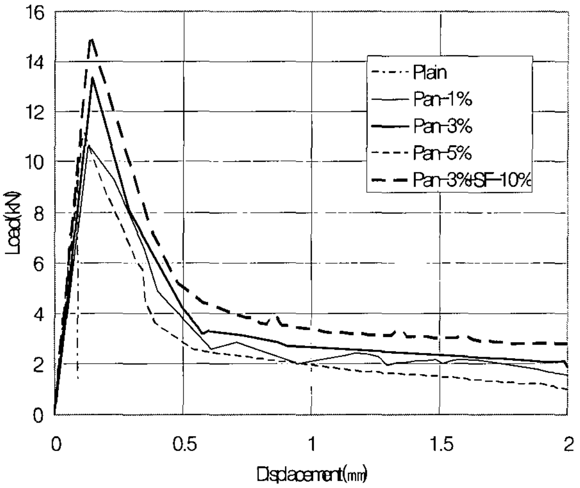

Fig. 12 Flexural load-displacement curves (PAN type CF)

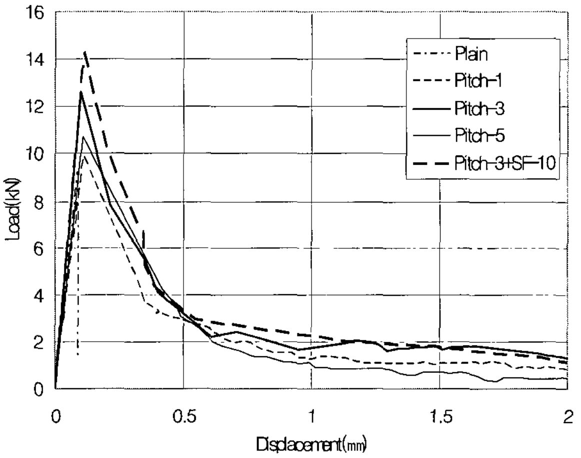

Fig. 13 Flexural load-displacement curves (Pitch type CF)

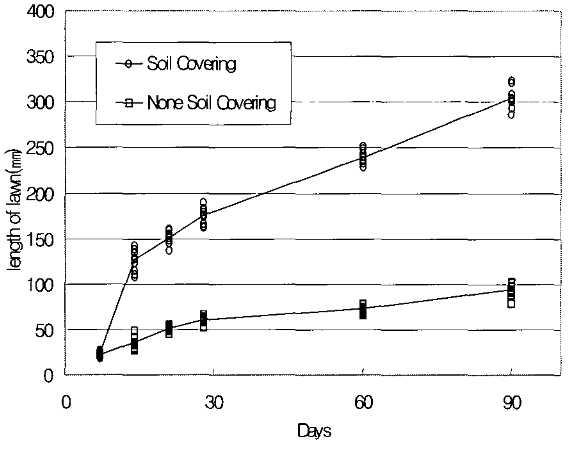

Fig. 14 Length of lawn by days

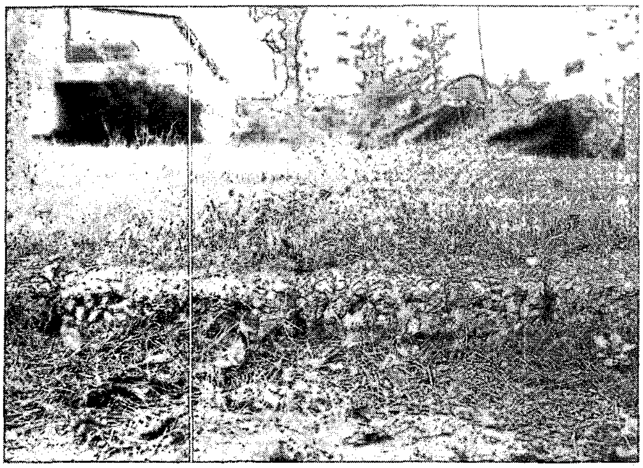

Photo 1 Three months after sprouting (Non Soil covering)

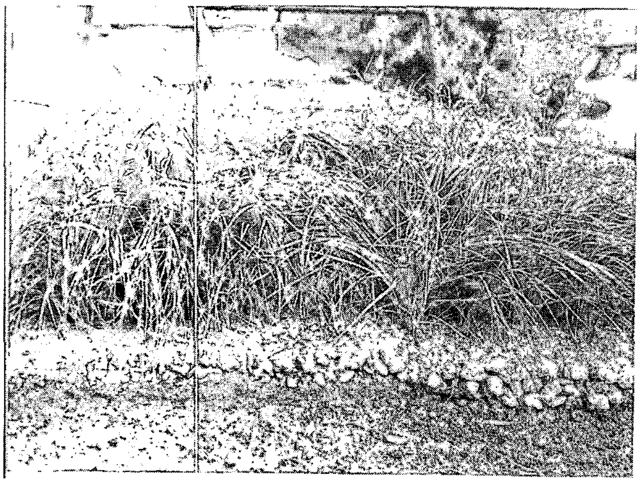

Photo 2 Three months after sprouting (Soil covering)

that until one week after sprouting, the status of growth of all the specimens was almost similar to each other regardless of the existence of soil covering. However, after two weeks, the grass on the soil covering showed better growth. In two weeks after sprouting, the length of grass growing on the soil covering reached 111.2mm to 143.2mm regardless of the concrete mix proportion. The grass on non-soil covered concrete grew to a length of 33.2mm to 41.5mm. In three months after sprouting, there was an approximate difference of 200mm found in the length of grass, depending on the existence of soil covering (Photo 1, Photo 2). Therefore, it was observed that the growth of plants on porous concrete was directly affected by the existence of soil covering when the particle size of aggregate and void of the soil covered concrete with that of non-soil covered concrete are similar.

4. Conclusions

The physical and mechanical properties of porous concrete and its application as a planting material were evaluated. The effects of additions of different proportion of recycled aggregate, silica fume and carbon fiber were investigate. The evaluation results are as follows

(1) The higher replacement ratio of recycled aggregate was, the less difference there was between void ratio and strength characteristics, compared to the case where recycled aggregate was not used.

(2) In case of using the silica fume, the mixing ratio of 10% silica fume was most effective for better strength.

(3) In case of using carbon fiber, the mixing ratio of 3% carbon fiber was good for the highest flexural strength and PAN-derived CF was much better than Pitch-derived CF.

(4) The evaluation of its use for vegetation proved that the growth of plants was directly affected by the existence of covering soil

Acknowledgment

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