Compressive Performance of 50MPa Strength Concrete Filled Square and Circular Tube(CFT) Columns Using Recycled Aggregate

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Abstract— ***In Korea, construction waste has been increasing steadily due to the redevelopment of aging buildings, and problems with aggregate supply and demand have been increasing due to limited natural aggregate reserves. The recycled aggregate is a solution to this problem, but when used as a structural member, the cement paste attached to the aggregate surface causes low compressive strength and high water absorption rate, which lowers the reuse rate. Therefore, we are trying to confirm the applicability of CFT columns to the actual building structural members by filling the concrete with recycled aggregate. In this study, we developed 50 MPa concrete and fabricated 18 specimens of CFT columns filled with recycled aggregate concrete. The parameters are the type of steel tube and the ratio of concrete strength to concrete strength. The compressive behavior of the cyclic aggregate concrete filled CFT column was analyzed through the load - displacement curves and the performance was verified by the existing strength equation of the international code.***

Index Terms—*recycled aggregate, CFT column, concrete filled tube, mixing ratio, 50MPa, compression performance*

I. INTRODUCTION

A. Research Background and Purpose

In the construction industry, the construction waste is increasing as shown in Table 1 due to social factors such as redevelopment and reconstruction, and deterioration and demolition of structures over 30 years due to deterioration of function and deterioration of buildings (Ministry of Environment 2016). In addition, due to the shortage of natural aggregate, aggregate supply and demand is getting worse day by day, so the social interest in recycled materials is increasing in terms of conservation of national resources and environmental preservation. However, in Korea, the research data of recycled aggregates and their field application results are very poor compared to advanced countries. In the case of Japan, research on the application of recycled aggregate from concrete waste has been actively conducted since the 1980s. In China (Han (2006)), studies on composite columns using recycled aggregate have also been actively conducted. The limiting reason for the application of structural components using recycled aggregate is the cement paste attached to the surface of the aggregate. The cement paste around the aggregate causes low fluidity and creep and shrinkage due to low initial age compressive strength and high water absorption rate of concrete, and negative recognition of recycled aggregate causes low

Table 1 Construction waste status (ton/d)

	'12	'13	'14
Amount of waste	186,629	183,538	185,382
Increase rate compared to last year	0.1	-1.7	1.0

recycling rate. Therefore, the weak point was compensated by using recycled aggregate concrete in the CFT steel tube. Specifically, the steel tube surrounding the recycled aggregate receives the initial strength instead of the steel tube, thereby stably expressing the internal recycled aggregate concrete and improving the long-term performance by reducing external influences. In addition, negative recognition of recycled aggregate can be positively improved through the proven structural performance of CFT.

Therefore, in this paper, we try to find out the recycled aggregate concrete with a compressive strength of 50 MPa by substituting 100% of the domestic recycled aggregate and verify that it is suitable for filled steel column. In addition, we confirmed the workability of concrete and strength development by filling square / round steel tubes and confirmed the possibility of the main structural member of recycled aggregate.

B. Research Content and Scope

In order to find the mixing ratio of 50 MPa of recycled aggregate concrete with 100% recycled aggregate, we adjusted the amount of mixing water. In order to find a mix design suitable for filling steel tube columns, we aimed at 500 ~ 700mm flow slump, The amount was adjusted during the experiment.

Two types of CFT steel tube were used to confirm the compressive behavior of the steel tube columns filled with the recycled aggregate concrete obtained by checking the compressive strength of the specimens. The stub column test was performed to minimize the buckling and to confirm the compressive behavior. The buckling shape of the specimen was confirmed and the load - displacement graph was drawn and analyzed. In addition, the CFT compressive strength equation of domestic and overseas codes was used to compare with the experimental results and the structural performance was confirmed.

II. PRECEDENT RESEARCH

A. *Applied to Structural Member of Recycled Aggregate Concrete*

In the case of Korea, the law for promoting the recycling of construction waste was enacted in 2003, and the quality standard of recycled aggregate for each recycling purpose was set. As a result, KS F2573, recycled aggregate concrete (11, 2009) was added to the concrete standard specification through the standardization of the recycled aggregate KS. In addition, there are many research papers for recycling recycled aggregate as a concrete material.

It was found from the 1998 experiment that the compressive strength was significantly increased when 20% of silica fume was incorporated (Lee, Sung-Je, 1998). Lee, Jin-Yong et al. Studied the effect of fly ash content on the properties and mechanical properties of concrete in 1999. Compression and tensile strengths were slightly lower than those of ordinary concrete in the 7th to 28th days of age, but they were much better at 180 days of long-term compressive strength (Lee, Jin-yong, 1999).

In a study on the effect of recycled aggregate and fly ash on concrete fluidity and strength in 2013, the compressive strength and splitting tensile strength of concrete using recycled aggregate tended to decrease with increasing replacement rate. Also, 30% replacement of recycled aggregate and concrete using fly ash were found to be helpful in improving long - term strength. (Kim, Kyuheon et al., 2013)

Meanwhile. In China, there has been intensive research on recycled aggregate concrete, and there have been many efforts to clarify the performance and suitability of structural members made of recycled aggregate concrete. (Xiao et al., 2012; Nixon, 1978; Casuccio et al., 2008;)

Li et al. (2006) conducted an experiment on the compressive strength of recycled aggregate concrete. As a result, the RCA content significantly affected the compressive strength of recycled aggregate concrete. The compressive strength of recycled aggregate concrete with 100% recycled aggregate was about 10% lower than the compressive strength of conventional concrete.

Based on these results, it was confirmed that it helps to improve the long - term compressive strength of recycled aggregate concrete containing fly ash and silica fume. Therefore, in this study, fly ash and silica fume were used in concrete formulations for long term strength development.

B. *Use of Recycled Aggregate Concrete for Steel Tube Filling*

A study on the recycled concrete filled tube column in which concrete using recycled aggregate is placed in a steel tube has not yet been conducted in Korea. In China, various mechanical properties and seismic performance of concrete

Table 2. Application range of composite columns in Korea and abroad

content	KBC2016	AISC 360-10	Eurocode 4
$A_{s.min}$	1% A_g	1% A_g	2%-9%
f'_c	21-70MPa	21-70MPa	20-50MPa
$F_{y.max}$	650MPa	525MPa	450MPa

□/○	□	○	□	○	□	○
B(D)/ t_{max}	λ_p		λ_p		$52\sqrt{\frac{235}{F_u}}$	$90\sqrt{\frac{235}{F_u}}$
	$2.26\sqrt{\frac{E}{F_y}}$	$0.15\frac{E}{F_y}$	$2.26\sqrt{\frac{E}{F_y}}$	$0.15\frac{E}{F_y}$		

CFT steel tube columns using recycled aggregate have been reported.

Yang and Han (2006) confirmed that the ultimate capacity of existing concrete is 1.7 ~ 9.1% higher than that of recycled aggregate concrete containing 50% recycled coarse aggregate because the strength of recycled aggregate concrete is low.

Chen et al. (2014) reported that the strength of recycled aggregate concrete filled steel columns increased with increasing RCA replacement ratio. It is confirmed that the strength of most recycled aggregate concrete filled steel tube columns increases with increasing replacement rate of recycled aggregate.

Therefore, a concrete tube (CFT) column filled with concrete with 100% recycled aggregate was fabricated and tested

III. STRENGTH FORMULA OF CFT COLUMNS FILLED WITH RECYCLED AGGREGATE

Composite structures that utilize two or more different materials to improve the overall performance by taking advantage of the properties of each material provide design guidelines in accordance with national regulations. Table 2 summarizes the application range of composite members at Korea and abroad (KBC, AISC, Eurocode).

In addition, the scope of application of the composite member design in both domestic and overseas covers general concrete, and there is no design rule for the composite structure of the recycled aggregate concrete yet.

A. *KBC(Korea Building Code) 2016*

In Korea, both rectangular and circular steel tubes used as test specimens were unified into compact sections. However, as mentioned above, there is no proof formula for CFT filled with recycled aggregate concrete in Korea. Therefore, using the formula of the CFT column filled with normal concrete,

$$(1)P_{no} = P_p$$
$$P_p = F_y A_s + F_{yr} A_{sr} + C_2 f_{ck} A_c$$
$$C_2 : (Square)0.85(Circular)0.85(1+1.56\frac{f_y t}{D_c f_{ck}})D_c$$

the compressive strength is expressed as follows (1). Through the analysis of the experimental results, the compressive strength of the CFT columns filled with the recycled aggregate concrete is evaluated and it is judged whether the use of general concrete strength formula is appropriate.

B. *AISC(American Institute of Steel Construction)360-10*

As with KBC2016, AISC 360-10 also divides the width ratio of the compression material into three types: compact / non-compact / slender. The concrete strength reduction factor is 0.85 for square and 0.95 for round. All the test specimens in this study are compact section, and the proof stress formula is the same as in Eq. (2).

$$(2) P_{no} = F_y A_s + C_2 f'_c (A_c + A_{sr} \frac{E_s}{E_c})$$

$$C_2 = (Square) 0.85, (Circular) 0.95$$

IV. EXTRACTION OF RECYCLED AGGREGATE CONCRETE MIXTURE RATIO FOR FILLED STEEL TUBE

A. *Experiment Plan*

In order to find the mixing ratio of recycled aggregate concrete suitable for CFT-filled steel tubes, an experimental plan was established as shown in Table 4 based on the results of the preliminary tests of the third stage. As the experimental parameters, the compressive strength of the recycled aggregate concrete was set to 30, 40, and 50, respectively. The experiment was divided into two stages according to the ratio of powder. Table 3 shows the formulation used in this experiment.

Table 3. Parameter of specimens

ID	f_{ck} (MPa)	OPC:SP:FA(%)
Type 1	30	100:0:0
Type 2	30	100:0:0
Type 3	40	70:20:10
Type 4	50	70:20:10

* OPC = Ordinary Portland Cement

* SP = Silica fume

* FA = Fly Ash

Table 4. Mix propotions and properties of recycled aggregate concrete

Type	Target strength, f_{ck} (MPa)	Cement (kg/m^3)	Silica Fume (kg/m^3)	Fly Ash (kg/m^3)	recycled sand (kg/m^3)	Recycled coarse aggregate (kg/m^3)	water (kg/m^3)	W/C	28-day strength, f_{ck} (MPa)
1	30	22.4	0	0	61.2	69.3	3.7	52%	30.4
2	30	22.4	0	0	61.2	69.3	3.7	52%	26.9
3	40	15.9	4.5	2.3	60.4	68.4	3.8	51%	40.9
4	50	21.8	6.2	3.1	56.4	63.8	4.3	49%	54.9

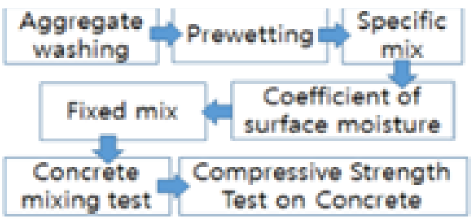


Fig. 1 Flow Chart of Recycled Aggregate Concrete Experiment

B. *Securing Strength and Fluidity of Recycled Aggregate Concrete*

Fig. 1 is a flow chart summarizing the process of making recycled aggregate concrete. The recycled aggregate and the impurities contained in the aggregate concrete were removed by washing 2-3 times. Aggregates were immersed in water before the experiment so that they could absorb enough water. Through the following procedure, we found the mixing ratio that can achieve the target strength of the recycled aggregate concrete through three preliminary mixing. In addition, the amount of high performance water reducing agent was observed and recorded to find the proper fluidity so that it could be filled tightly in the CFT steel tube. Based on KS F 2402, a flow slump of 500 to 700 mm was formulated as a target slump. Recycled aggregate concrete specimens were 100 mm in diameter and 200 mm in height and were subjected to a mixing test according to KS F 2403 as shown in Fig. 2. Compressive strength measurements were carried out on 3 days, 7 days, 14 days and 28 days, respectively. 3, the compressive strength was confirmed by applying a compressive stress increasing rate of 0.6 to 0.4 MPa per second according to KS F 2405 (Concrete Compressive Strength Test Method).

Fig. 2 Specimen curing

Fig. 3 Experiments of compressive strength of specimens

Section Type	No.	f_{ck}	Mix type	λ_p	λ_r	λ	D(b
	SA-1	X		95.2	120.6	37.5	
	SB-1	30MPa	OPC 100%				
	SB-2						
	SB-3						
Square	SB-4						

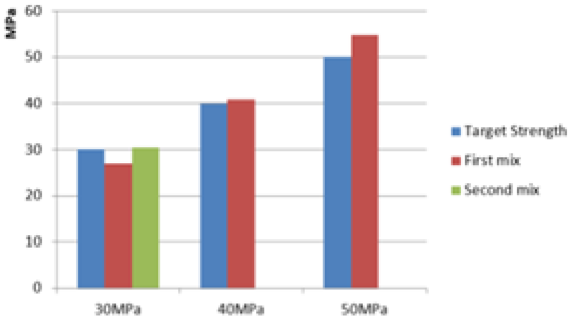


Fig 4. Concrete mixture results

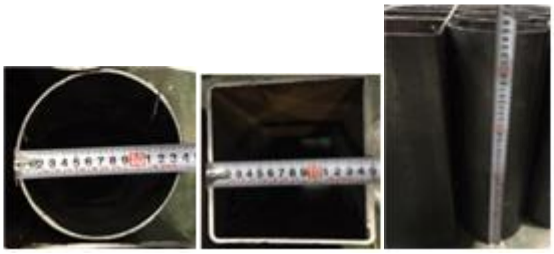


Fig. 5 Steel pipe material

Fig. 6 Recycled aggregate concrete filling CFT column curing

C. *Experiment result*

Fig. 4 shows the compressive strength comparison graph in the recycled aggregate concrete formulations. Two types of concrete with a design strength of 30 MPa 30.4 MPa, 27 MPa, 40 MPa concrete with a design strength of 40 MPa and 54.9 MPa concrete with a design strength of 50 MPa, respectively.

V. CFT COLUMN COMPRESSION TEST FILLED WITH RECYCLED AGGREGATE CONCRETE

A. *Experiment Plan*

A total of 18 specimens were designed to investigate the structural performance of CFT columns filled with recycled aggregate. The main variables are the shape of the steel tube and the composition of the recycled aggregate concrete filled inside. The steel tube was made of 4 mm steel plate of SPSR400 steel type and the round plate steel of 2.7 mm thickness of SPS260 steel type, as shown in Fig 5. The rectangular steel tube had a dimension of □ 150 × 150 × 4, a circle of -139.8 × 2.7, and a member length of 450 mm in both square and circular. Table 5 summarizes all the test specimens. The experimental parameters were classified according to the type of steel tube, the compressive strength of the concrete, and the ratio of the concrete mix. Fig. 6 is a picture of curing after pouring concrete into a steel tube.

B. *Material test result of steel*

Tensile test specimens of steel were manufactured in accordance with KS B0801, with 5 pieces of square steel tubes and 14B of round steel tubes. Table 6 shows the yield strength (), tensile strength (), yield ratio () and elongation (%) of the specimens.

Table 6. Results of coupon test

Thickness	F_y (MPa)	F_u (MPa)	F_y / F_u (%)	Elongation (%)
□ - 4mm	260	359.61	72.3	30
○ - 2.7mm	310	471.92	65.8	21

C. *Compression Test Method for Columns of Steel Tube filled With Recycled Aggregate Concrete*

The maximum load capacity of the specimen was checked and the yield behavior was investigated. All recycled aggregate concrete filled steel tube columns were carried out at Keimyung University Advanced Construction Materials Testing Center. The experiment was performed as shown in Fig. 7 using 5,000 kN capacity UTM. Load - axial displacement measurements were performed up to 80% of the maximum column strength.

Fig. 7 Column compression test

D. Maximum Strength and Initial Stiffness

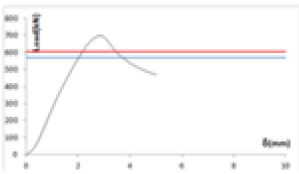
Table 7 summarizes the maximum strength, displacement and initial stiffness of each specimen. The initial stiffness is defined as a quadrant connecting the 45% point of maximum strength and the origin.

Table 7. Expermiental result

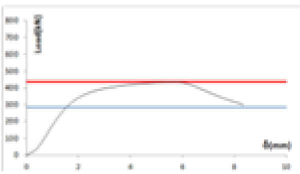
Specimen	Maximum load (kN) [C]	Axial displacement(mm)	Initial stiffness (kN/mm)
SA-1	699.1	2.9	276
SB-1	1187.3	5.4	191.5
SB-2	1169.5	3.9	302.3
SB-3	1161.2	5.7	241.9
SB-4	1176.6	4.9	221.5
SC-1	1145	6.1	237.5
SC-2	1237.1	3.6	381.8
SD-1	1248.5	5.9	267.4
SD-2	1525.7	4.1	361.4
CA-1	436.4	5.6	180.2
CB-1	900.6	16.1	210
CB-2	865.6	15.6	186.4
CB-3	914	14.5	321
CB-4	788.1	12.7	257
CC-1	789.6	7.4	306.8
CC-2	906.5	12.9	259.8
CD-1	1127.9	6.3	307.6
CD-2	1078.1	5.1	303.6

E. Load-Displacement Graph

The relationship between compressive load and column displacement is shown in Fig. 8 and 9, respectively. In Tables 8 and 9, the blue line is the expected strength at the nominal strength and the red line is the expected strength at which the material test values are applied. It can be confirmed that most of the test specimens of round and square steel tubes have reached the maximum load exceeding the expected strength. Fig. 8 is a load-displacement graph of square and circular steel tubes for unfilled steel tube.

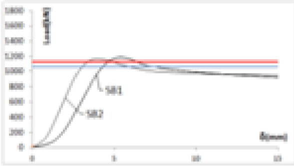


(a) SA-1

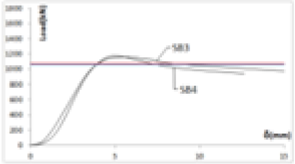


(b) CA-1

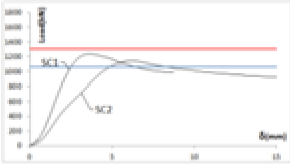
Fig. 8 Unfilled steel pipe load-displacement curve graph



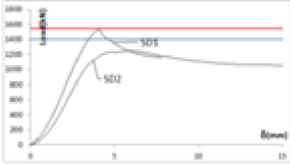
(a) SB-1, SB-2



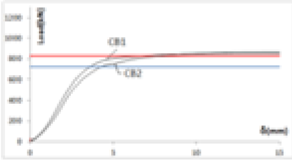
(b) SB-3, SB-4



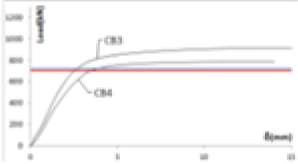
(c) SC-1, SC-2



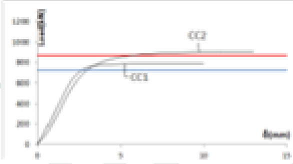
(d) SD-1, SD-2



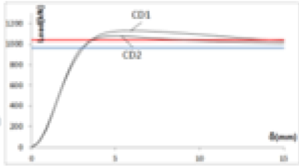
(e) CB-1,CB-2



(f) CB-3,CB-4



(g) CC-1,CC-2



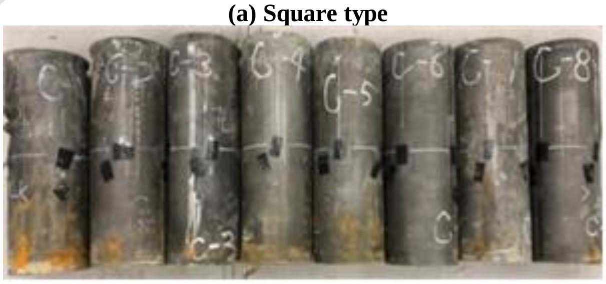
(h) CD-1,CD-2

Fig. 9 CFT column load-displacement curve graph

F. Fracture Shape of Specimen

Fig. 10 is a diagram for comparing the failure modes of all specimens after the test. Most of the specimens buckled after reaching the maximum load after compressive load application. After reaching the maximum load, the compression test was performed up to 80% of the maximum load. It can be confirmed that buckling occurred at the upper part of all columns of the filled steel tube columns. The specimens buckled several times showed the load drop after reaching the maximum load. After that, it was ascertained that the buckling occurred a number of times while repeating the process of dropping again after receiving the strength.

(a) Square type



(b) Circle type

Fig. 10 Compressive failure mode of CFT column

VI. ANALYSIS AND DISCUSSION

A. Securing 50MPa Recycled Aggregate Concrete for Filled Steel Tube

In this experiment, we tried to mix 100% recycled aggregate concrete for CFT filling. A high performance water reducing agent was used to find the target strength and available fluidity in the CFT. Four types of concrete mix were obtained through three preliminary blending and main blending, and the compressive strengths were confirmed through the specimens. The results are summarized in Table 8. It was confirmed that the compressive strength of concrete using 100% recycled aggregate for the filled steel tube was 50 MPa.

B. Compressive Strength Analysis of Reinforced Concrete Filled Steel Tube Columns with Compact Section

Table 9 compares the expected maximum yield strength with the nominal strength of the specimen, the expected maximum yield strength, and the maximum load using Eq. (1) according to KBC2016. In addition, we have summarized the result value and anticipated capacity so that they can be compared with each other. A / C shows that most of the specimens showed a range of 0.81 ~ 1.16% compared with the expected strength.

Table 8. Strength properties of recycled aggregate concrete

specified concrete strength	30MPa		40MPa	50MPa
Compressive strength of concrete cured for 28 days	30.4	27	40.9	54.9
Compressive Strength Accuracy of Concrete	(101%)	(90%)	(102%)	(109%)

Table 9. Experiment result

Specimen	P_u (kN) [A]	KBC2016 (kN)[B] / (A/B)	AISC360-10 (kN)[C] / (A/C)	Eurocode 4 (kN)[D] / (A/D)
SB-1	1187.3	1127.4/(1.05)	1128/(1.05)	1219.9/(0.97)
SB-2	1169.5	1127.4/(1.04)	1128/(1.04)	1219.9/(0.96)
SB-3	1161.2	1069.6/(1.09)	1068.1/(1.09)	1149.4/(1.01)
SB-4	1176.6	1069.6/(1.10)	1068.1/(1.05)	1149.4/(1.02)
SC-1	1145	1307.9/(0.88)	1307.8/(0.88)	1431.51/(0.8)
SC-2	1237.1	1307.9/(0.95)	1307.8/(0.95)	1431.51/(0.86)
SD-1	1248.5	1547/(0.81)	1547.7/(0.81)	1713.61/(0.73)
SD-2	1525.7	1547/(0.99)	1547.7/(0.99)	1713.61/(0.89)
average		1.08	0.99	0.91
CB-1	900.6	827.9/(1.09)	769.8/(1.17)	954.3/(0.94)
CB-2	865.6	827.9/(1.05)	769.8/(1.12)	954.3/(0.90)
CB-3	914	787.3/(1.16)	722.7/(1.26)	908.3/(1.00)
CB-4	788.1	787.3/(1.00)	722.7/(1.09)	908.3/(0.87)
CC-1	789.6	955/(0.83)	911.3/(0.87)	1093.2/(0.72)
CC-2	906.5	955/(0.95)	911.3/(0.99)	1093.2/(0.83)
CD-1	1127.9	1123.2/(1.00)	1099.9/(1.03)	1279.96/(0.88)
CD-2	1078.1	1123.2/(0.96)	1099.9/(0.98)	1279.96/(0.84)
average		1.18	1.06	0.87

C. Review of Current Design Formula and Experimental Value

The structural performance is verified by comparing the experimental results with the current design formulas. Table 10 compares the design compressive strength of the composite column subjected to axial load in the current design formula (KBC2016) and AISC360-10 and Eurocode 4. Compared with KBC 2016, the design formula and experimental value were 0.88 ~ 1.10% for rectangular steel tube and 0.83 ~ 1.16 for circular steel tube. Compared with the design formula of ASIC360-10, it was 0.81 ~ 1.09% for rectangular steel tube, 0.87 ~ 1.26 for circular steel tube, 0.8 ~ 1.02% for square steel tube compared with Eurocode 4 design formula and 0.84 ~ 1.23 for the round steel tube.

VII. CONCLUSION

In order to evaluate the performance of recycled aggregate concrete and the compressive strength of CFT steel tube columns filled with concrete using recycled aggregate, four concrete formulations and CFT column center compression tests were conducted and the following conclusions were drawn.

1. Experiments of recycled aggregate concrete showed that it is possible to develop strength up to compressive strength of 50 MPa for the purpose of filling CFT steel tube with 100% of recycled aggregate in Korea.

2. The compressive performance of the recylced aggregate concrete filled steel column with a compact section was evaluated, and it was confirmed that the ratio of the maximum load to the predicted yield strength calculated from the existing strength formula ranged from 81% to 116%.

3. The strength of the recycled aggregate concrete was 100% at 30 MPa, but it was less than 100% at 40 MPa and 50 MPa. It is necessary to use the strength reduction factor.

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