Available online at www.sciencedirect.com

SCIENCE DIRECT

Cement and Concrete Research 35 (2005) 1846–1854

Cement and Concrete Research

Studies on the sound absorption characteristics of porous concrete based on the content of recycled aggregate and target void ratio

Seung Bum Park*, Dae Seuk Seo, Jun Lee

Dept. of Civil Engineering, Chungnam National University, Daejeon, South Korea

Received 25 May 2004; accepted 16 December 2004

Abstract

This study performed an evaluation of the physical and mechanical properties and sound absorption characteristics of porous concrete. Design was based on the target void ratio and the content of recycled aggregate. The objectives are to reduce noise generated in roads, railroads, residential and downtown areas as well as to utilize recycled waste concrete aggregate. The test results demonstrated that the difference between the target void ratio and the measured void ratio was less than 1.7%. The compressive strength reduced rapidly when the target void ratio and the content of the recycled aggregate exceeded 25% and 50%, respectively. The sound absorption characteristics of the porous concrete using recycled waste concrete aggregate showed that the Noise Reduction Coefficient (NRC) was optimum at the void ratio of 25% but the percent content of the recycled aggregate had very little influence on the NRC. Therefore, the optimum void ratio is 25% and the recycled aggregate is 50%.

Keywords: Porous concrete; Sound absorption; Recycled aggregate; Target void ratio

1. Introduction

Recently, improvements in the standard of living in industrial area require the establishment of a convenient residential environment in order to enhance the quality of living. To achieve such an environment, it is necessary to effectively reduce or prevent various environmental problems occurring in and around residential areas. These include air pollution, water pollution, soil contamination, noise, vibration, ground settlement, offensive odors, etc. From among these, traffic noise created by the development of new roads due to the recent rapid increase in vehicle ownership has become a serious environmental problem. Therefore, to overcome this problem, a type of concrete needs to be developed that cannot only create visual harmony with the surrounding natural environment but also aid in the reduction of environmental load such as noise. From this view point, focus is turned toward the development of multi-functional porous concrete having water and air permeability, good sound absorption ability, etc., by artificially forming continuous porosity using coarse aggregate of single size rather than the more traditional fine aggregate [1–4].

In addition, of the 39 million tons of construction wastes generated from construction sites due to urban renewal projects and expansion of social infrastructures, waste concrete amounts to 24 million tons [5]. Such waste concrete is used as subgrade and landfill material and recycled into bricks for sidewalk pavement. However, due to the insufficient recycling facilities and difficulty in securing good quality waste concrete for recycling, more than 90% of waste concrete is used as subgrade material. Therefore, considering our current domestic situation involving the shortage of natural aggregate resources, a study on the use of the waste concrete as an alternative aggregate with a view to effective utilization of the resource and environmental protection is in urgent need.

Thus, in order to examine the effective use of recycled waste concrete aggregate and its applicability to porous concrete as a sound absorption material, this study examined

* Corresponding author. Tel.: +82 42 821 5674; fax: +82 42 822 6265.
E-mail address: park_sb@cnu.ac.kr (S.B. Park).

0008-8846/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconres.2004.12.009

the physical and mechanical properties of porous concrete according to the recycled aggregate content and target void ratio and analyzed its sound absorption characteristics using the impedance tube method and the reverberation room method.

2. Experimental work

Table 1 shows the conditions and variables of the experiment to examine the physical, mechanical and sound absorbing characteristics of porous concrete according to the target void ratio (TVR) and the recycled aggregate content (RAC). The amount of admixture added to obtain fluidity was determined by means of a flow test.

2.1. Materials

The cement used for this study is normal portland cement whose specific gravity is 3.14 and blaine fineness is 3200 cm^2/g, containing 21.4% of SiO_2, 5.97% of Al_2O_3 and 62.72% of CaO.

Crushed aggregate and recycled waste concrete aggregate of 5–13mm in size are used. Table 2 shows their physical properties.

The admixture was a highly polymerized naphthalene sulphonate, which is a type of the super plasticizer (Mighty-150) that improves the concrete quality through cement distribution action, see Table 3.

2.2. Test method

In order to determine the amount of the super plasticizer, the KS L 5111 flow table test was used. This test determines the required workability when manufacturing porous concrete, prevents material separation and forms continuous porosity after hardening.

The experiment to determine void ratio was performed based on "Porous concrete void ratio experiment method (draft)" [6]. The void ratio was calculated using Eq. (1).

$$A\ (\%) = \{1 - (W_2 - W_1)/V_1\} \times 100 \quad (1)$$

where, A: total void ratio of concrete, W_1: weight of the specimen under water, W_2: weight of the specimen following 24 h exposure to the air, V_1: volume of the specimen.

The porous concrete compressive strength experiment was performed based on "Method of test for compressive strength of concrete", KS F 2405, with a specimen of 10×20 cm using a universal hydraulic testing device.

In order to evaluate the sound absorption characteristics according to the target void ratio and the content of recycled aggregate, the absorption coefficient was measured for the specimen of 9.8×10 cm for each frequency using an impedance tube as shown in Fig. 1 based on "Determination of sound absorption coefficient and impedance in impedance tubes: Part 1. Method using standing wave ratio", KS F 2814-1, [7]. The Noise Reduction Coefficient (NRC) was then obtained by calculating the arithmetic mean of the absorption coefficients at 250 Hz, 500 Hz, 1000 Hz and 2000 Hz. Moreover, in order to evaluate the sound absorption ability of the porous concrete within the range of 250–2000 Hz, the Sound Absorption Area Ratio (SAA) [8] was calculated using the absorption coefficient curves in Fig. 2 and Eq. (2). It was then compared with the NRC.

$$\mathrm{SAA} = \mathrm{Ai}/\mathrm{Ao},\ \mathrm{Ai} = \int Y(X)\mathrm{d}x \\ Y = AX^3 + BX^2 + CX + D \quad (2)$$

where, SAA: sound absorption area ratio, Ao: area of ABCD, X: Hz, Ai: area of AEFD, Y: absorption coefficient.

In order to examine the applicability of porous concrete as a sound absorption material, panel shaped specimens of 50×50×10 cm were constructed and the panels were installed in a reverberation room. The total area of the panels installed were 12 m^2. Then, the reverberation time without the specimen (T_1) and the reverberation time with the specimen (T_2) were measured in the range of the center frequency based on the

Table 1
Conditions and variables of experiment

Conditions	Variables
W/C (%)	25
Target void ratio (%)	20, 25, 30
Target flow (%)	200
Aggregate	Crushed and recycled aggregate Gradation: 5–13 mm
Content of recycled aggregate (vol.%)	30, 50, 100
Test items	
Physical and mechanical properties	Void ratio Compressive strength
Sound absorption coefficient	Method of impedance tubes Method of reverberation room

Table 2
Physical properties of aggregate

Items	Gradation (mm)	Density (g/cm^3)	Water absorption (%)	Absolute volume (%)	Unit weight (kg/m^3)
Crushed aggregate	5–13 mm	2.55	1.20	55.6	1480
Recycled aggregate		2.34	4.1	57.5	1402

Table 3
Physical properties of admixture

Type	Appearance	Density (g/cm^3)	Ph	Content of solid (%)
Super plasticizer (Mighty-150)	Dark brown liquid	1.20	7–9	41–45

Fig. 1. Measurement of absorption coefficient by impedance tubes.

"Method for measurement of sound absorption coefficients in a reverberation room" of ISO 354 [9] and KS F 2805 [10]. The sound absorption area in the range of specific frequency was obtained using the volume of the specimen and the characteristic value (c) and then it was divided by the area of the reverberation room (S) to obtain the absorption coefficient (a_r) in the reverberation room using Eq. (3).

$$A\ (\%) = 5.53\frac{V}{c}\left(\frac{1}{T_2} - \frac{1}{T_1}\right),\ a_r = \frac{A}{S} \quad (3)$$

2.3. Mix proportion and mixing

In order to analyze the physical and mechanical properties as well as the sound absorption characteristics of porous concrete according to the mix proportion, the concrete was mixed according to the desired void ratio and recycled aggregate content for the W/C of 0.25, see Table 4. In order to enhance the dispersability of the cement paste, mixing was performed by combining the cement and water (water+ admixture) and premixing at 200 rpm for 270 s using a 30 l omni-mixer. Next, the aggregate was added and mixed for 90 s.

2.4. Preparation of test specimens

Specimens were constructed by the "Method to Make Porous Concrete Specimens (craft)" of the ECO Concrete Research Committee in Japan. When mixing was completed, the porous concrete was filled into each mould and it

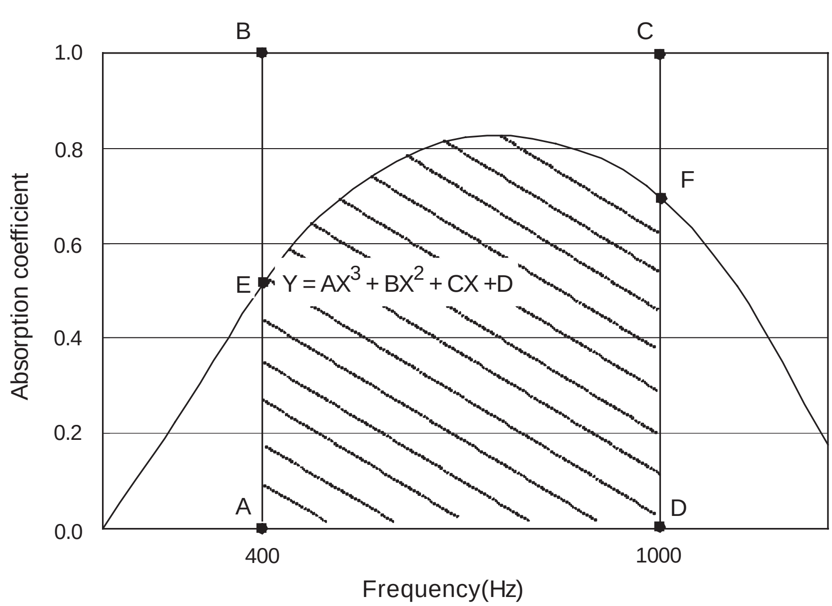

Fig. 2. Evaluation method of SAA (sound absorption area ratio).

Table 4
Mix proportions of porous concrete

Mix no.	Aggregate gradation (mm)	*W*/*C*	Target void ratio (%)	RA content (vol.%)	Unit weight(kg/m^3)				
					W	*C*	CA	RA	SP
I-1	5–13	0.25	20	–	107	430	1480	–	2.47
I-1				30	105	419	1003	453	2.41
I-1				50	103	413	739	698	2.38
I-1				100	99	396	–	1402	2.29
II-1			25	–	85	342	1480	–	1.98
II-2				30	83	331	1003	453	1.93
II-3				50	81	325	739	698	1.89
II-4				100	77	308	–	1402	1.80
III-1			30	–	63	253	1480	–	1.50
III-2				30	60	243	1003	453	1.45
III-3				50	59	237	739	698	1.41
III-4				100	55	220	–	1402	1.32

I series: target void ratio 20%, II series: target void ratio 25%, III series: target void ratio 30%.
CA: crushed aggregate, RA: recycled aggregate, SP: super plasticizer.

was compacted twice by vibration using a vibration table at half-full and when full. The porous concrete specimens were stripped from the moulds after dry curing for 48 h and then in 20±3 °C water.

3. Test results and discussions

3.1. Void ratio

Fig. 3 demonstrates the measurement results, the TVR and the RAC. The figure indicates that the actual measured void ratios were 18.4–21.1%, 23.7–26.1% and 28.3–31.5% for TVRs of 20%, 25% and 30%, respectively. Since the difference between the target void ratio and the actual measured void ratio was found to be maximum 1.7%, the mixing method and compacting method used in this study are considered to be appropriate. In addition, there was only a slight influence on the void ratio by increasing the content of the recycled aggregate.

3.2. Compressive strength

Fig. 4 demonstrates the test results of the compressive strength of the porous concrete according to the target void ratio and the content of the recycled aggregate. It reveals that (1) the compressive strength tends to decrease regardless of the percent content of the recycled aggregate as the TVR increases and (2) the tendency of compressive strength to decrease is extreme when the TVR exceeds 25%. Moreover, the compressive strength of porous concrete tends to decrease for the TVR as the content of RAC increases. As the content of the RAC increased to 30%, 50% and 100% for the TVRs of 20%, 25% and 30%, respectively, the compressive strength was reduced by 4.1–16.0%, 2.6–16.1% and 2.9–15.0%

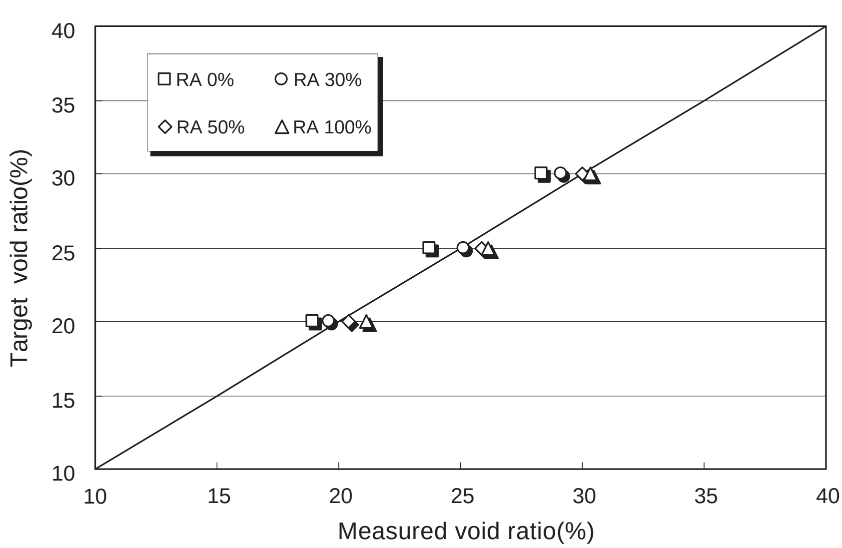

Fig. 3. Actual measured void ratio by RA content.

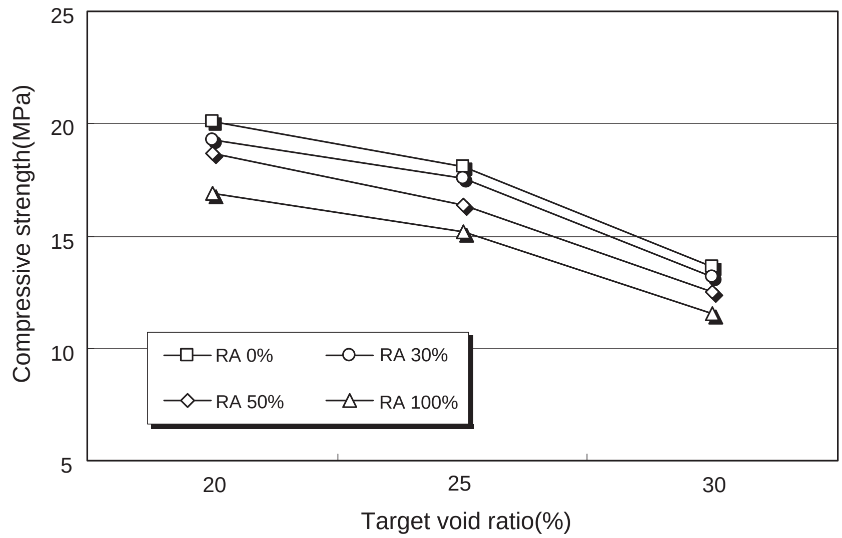

Fig. 4. Compressive strength by RA content and target void ratio.

relative to concrete containing no recycled aggregate. The compressive strength reduced markedly when the content of the recycled aggregate exceeded 50%. This is considered to be due to reduction of bonding between aggregate and cement paste when using recycled aggregate.

3.3. Sound absorption characteristics of the porous concrete by impedance tube

In order to analyze the sound absorption characteristics of porous concrete according to the target void ratio and the recycled aggregate, the absorption coefficient was measured for each frequency using an impedance tube. The measurement results are shown in Figs. 5–8. It can be seen from (1) the results that for the TVR of 20%, the absorption coefficient became highest in the frequency range of 315–400 Hz; (2) for the TVR of 25%, it became highest in the frequency range of 400–500 Hz; and for the TVR 30%, it became highest in the frequency range of 500–630 Hz. This signifies that the frequency of the highest absorption coefficient was obtained sound as the TVR increased. This is corroborated by studies [11,12] of Nakajawa and others in Japan. This is because absorption became higher as the specific surface area of voids increased. Therefore, the specific surface area of the voids increased as the TVR of the porous concrete increased resulting in the highest sound absorption coefficient. Moreover, it was found that when the TVR remained the same, the increase in the content of the recycled aggregate had very slight influence on the

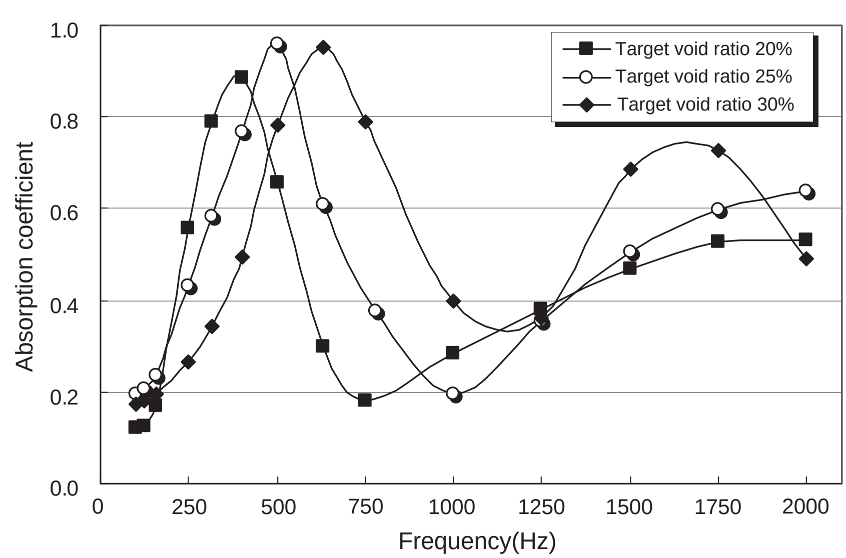

Fig. 5. Absorption coefficient by target void ratio (RA content 0%).

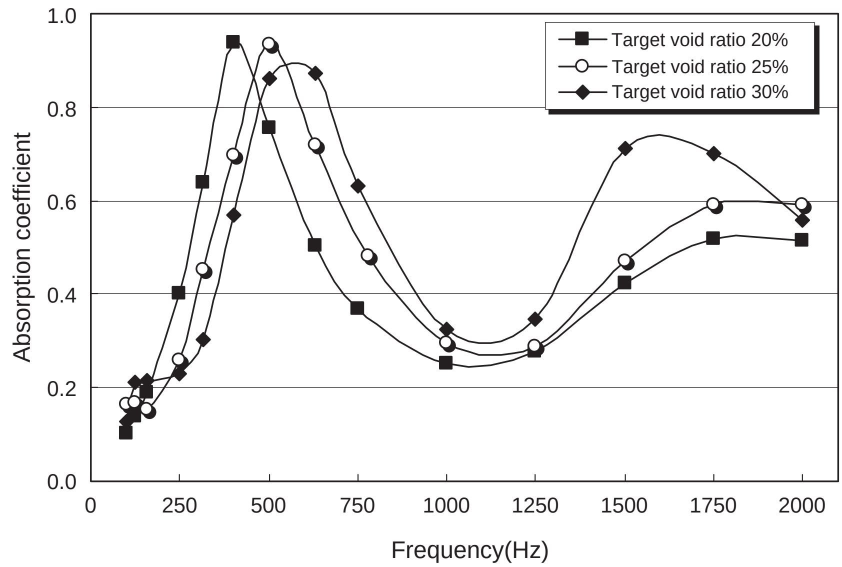

Fig. 6. Absorption coefficient by target void ratio (RA content 30%).

absorption characteristics of the porous concrete. There is little difference between the target void ratio and the actual measurement void ratio due to the increase in the content of the recycled aggregate.

Fig. 9 shows the NRC measurement result, which is the arithmetic mean of the absorption coefficients of the porous concrete using recycled aggregate at 250 Hz, 500 Hz, 1000 Hz and 2000 Hz. From this it can be seen that the NRCs were 0.48–0.51, 0.52–0.56 and 0.47–0.49 for the target void ratios of 20%, 25% and 30%, respectively, demonstrating that the tendency of the NRC was to increase as the TVR increased from 20% to 25%. It is shown that the NRC at the TVR of 30% was smaller than that at the TVR of 25%. The reason that the NRC was the highest at the TVR of 25% is thought to be that the absorption coefficient was the highest at 500 Hz, which is the frequency applied when calculating the NRC. Also, the sound absorption characteristics were better at 1000 Hz than those for other void ratios and the NRC was relatively low for the TVRs of 20% and 30% compared to the NRC for the TVR of 25%, with the absorption coefficient being highest in the range of 315–400 Hz and 500–630 Hz, which are not applied when calculating the NRC.

Fig. 10 depicts the sound absorption area ratio (SAA) of porous concrete using recycled aggregate at 250–2000 Hz. From this it can be seen that the SAAs were 41.3–45.7%, 49.1–50.5% and 53.7–59.4% for the TVRs of 20%, 25% and 30%, respectively, showing the tendency for SAA to increase along with an increase in the TVR. This is thought

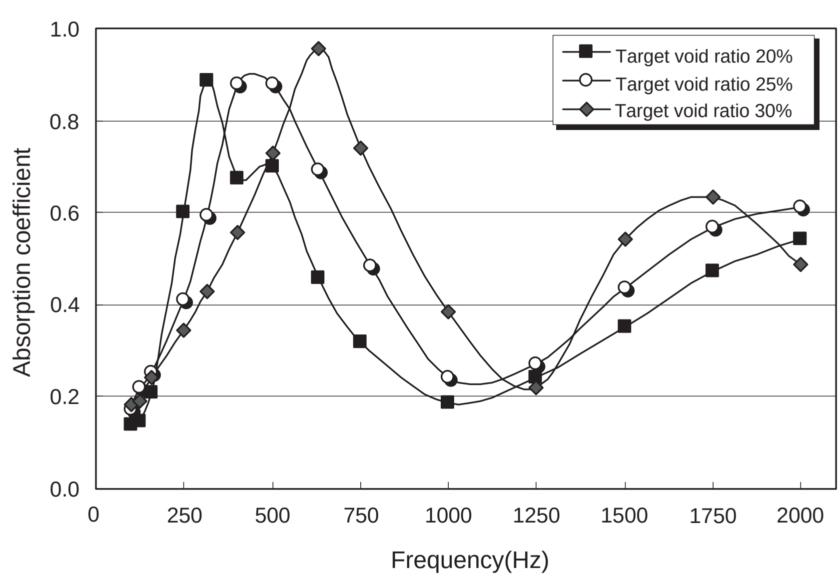

Fig. 7. Absorption coefficient by target void ratio (RA content 50%).

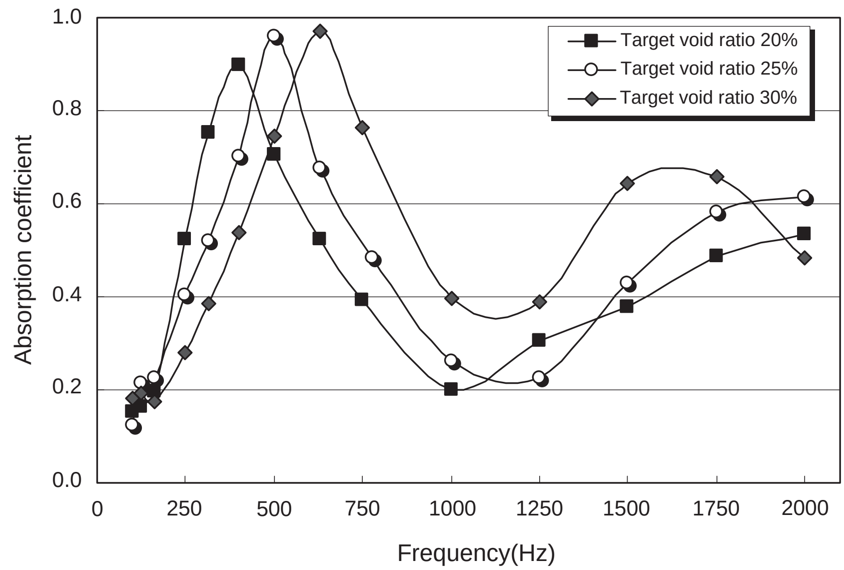

Fig. 8. Absorption coefficient by target void ratio (RA content 100%).

to be attributed to the ability of porous concrete to convert the incident noise energy into heat energy and other types of energy by vibration, friction, air viscosity, etc. As well, consumption of the energy was improved since the specific surface area of the void created inside the specimen increased as the TVR increased. As such, the reason that the tendency of the NRC and SAA according to the change in the TVR was different is thought to be because the NRC was expressed by the mean value of the absorption coefficients at specific frequencies, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and the SAA was expressed by the ratio of sound absorption areas measured at frequencies ranging from 250 Hz to 2000 Hz to the entire area. Therefore, when expressing the overall sound absorption ability in the range of 250–2000 Hz, the SAA may be the more accurate index. However, since the sound absorption ability is expressed by the NRC in the current regulations and specifications for sound proofing walls against noise pollution, it is recommended to analyze the sound absorption characteristics of the specimen using NRC and apply it when creating a prototype for field application.

3.4. Sound absorption characteristics of the prototype for field application by reverberation room method

In order to evaluate the characteristics of the porous concrete prototype for field application using recycled aggregate, the prototype was made with the RAC at 50%

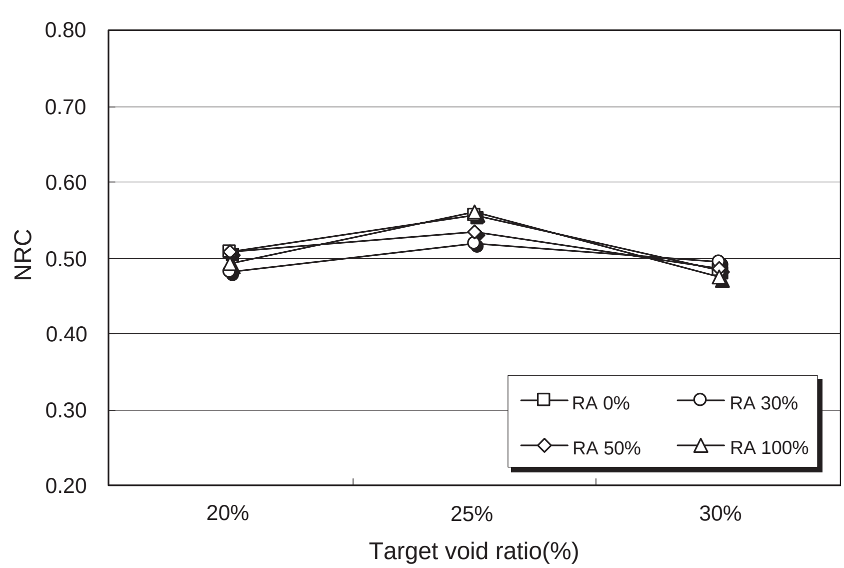

Fig. 9. NRC by RA content and target void ratio.

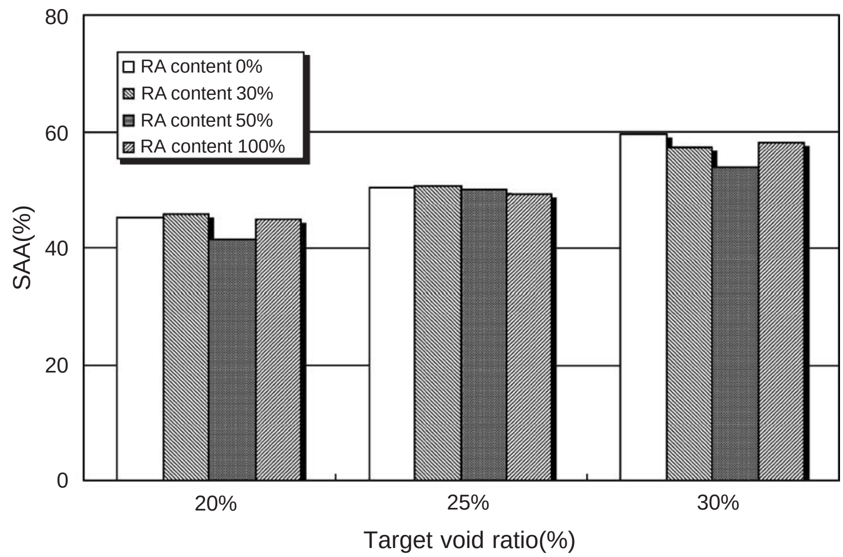

Fig. 10. SAA by RA content and target void ratio.

and the TVR at 25%. The porous concrete demonstrated superior characteristics in the physical and mechanical test and sound absorption test using an impedance tube. In order to evaluate the sound absorption ability under the conditions identical to the actual site conditions, it was installed in the reverberation room as shown in Fig. 12 and the sound absorption ability test was performed using the reverberation room method. Fig. 11 shows the test results.

From this it was discovered that the absorption coefficient tended to decrease a little at 500 Hz and 2000 Hz, however, as a whole it tended to increase from 0.12 to 0.86 as the center frequency increased from 100 Hz to 5000 Hz. In addition, the NRC of the prototype, which was measured by the reverberation room method, was 0.6. This was relatively higher than the NRC (0.53) by impedance tube of the same mix proportion. This is believed to be a result of the difference in the test conditions as well as the environment of the impedance tube method and reverberation room method (Fig. 12).

4. Conclusions

The results of the sound absorption of porous concrete according to the TVR and RAC are as follows:

(1) The difference between the target void ratio and the actual measured void ratio of porous concrete for noise reduction using recycled waste concrete aggregate of 5–13 mm in size was less than 1.7% and the

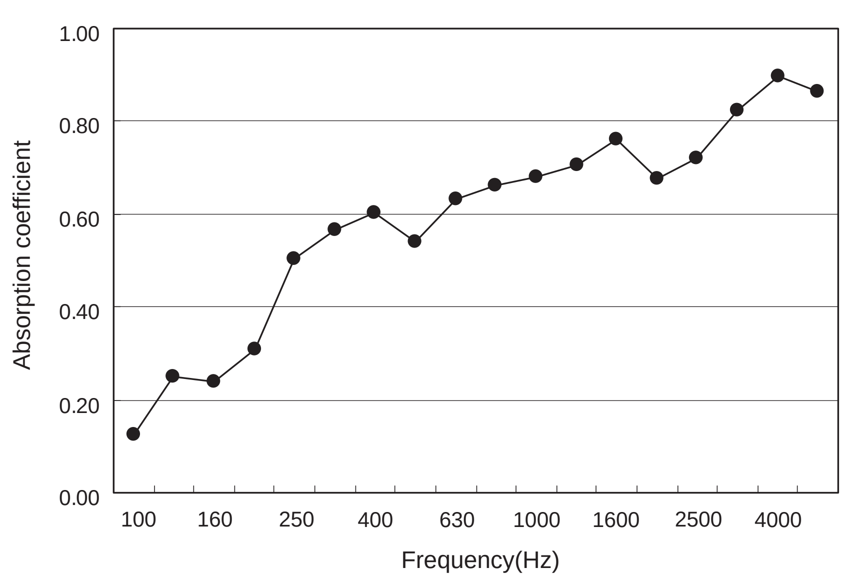

Fig. 11. Absorption coefficient by method of reverberation room.

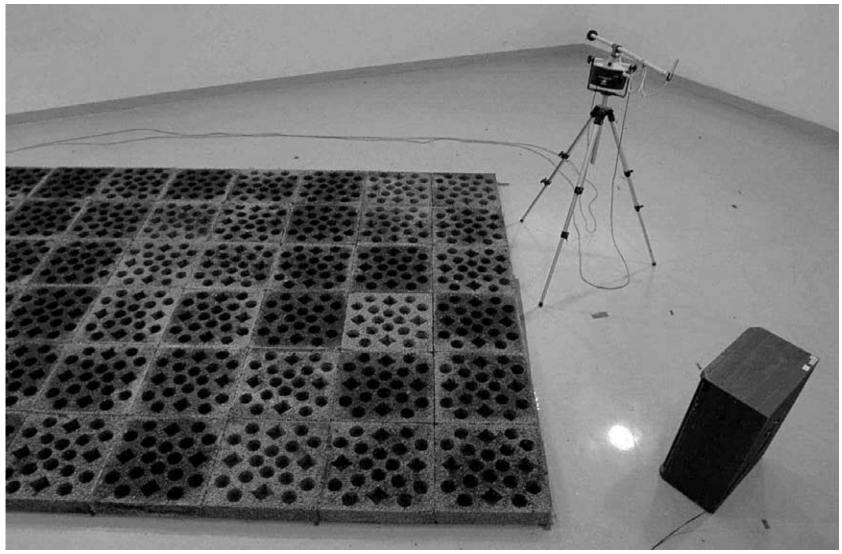

Fig. 12. Measurement of absorption coefficient in a reverberation room.

content of the recycled aggregate had little influence on the void ratio.

(2) The compressive strength of the sound absorbing porous concrete using recycled aggregate decreased as the TVR and RAC increased and it had a greatest tendency to decrease when the TVR and the content of the RAC exceeded 25% and 50%, respectively.

(3) The sound absorption characteristics of the porous concrete by the impedance tube demonstrated the frequency range where the absorption coefficient is optimum moved to the high frequency range as the TVR increased and the NRC was the highest at the value of 25%. However, the sound absorption area ratio (SAA) increased as the target void ratio increased, becoming the highest when the target void ratio was 30%.

(4) It was established that the sound absorption ability of the porous concrete prototype for field application designed to have the target void ratio of 25% and content of the recycled aggregate of 50% by the reverberation room method increased from 0.12 to 0.86 as the center frequency increased from 100 Hz to 5000 Hz and that the NRC was 0.6.

Acknowledgment

This work was supported by Grant No. R01-2004-000-10153-0 from KOSEF.

References

[1] S.B. Park, The present state and future views of environmentally friendly concrete for circulating society, J. Korea Concr. Inst. 15 (6) (2003) 14–16.

[2] S.B. Park, Concrete for sound absorption, J. Korea Concr. Inst. 12 (5) (2000) 33–37.

[3] S.B. Park, et al., The Report of Development of Noise Reducing Wall Using Cement Industrial by-Products, Ministry of Commerce, Industry and Energy, Seoul, 2003.

[4] T. Akito, O. Atsuhisa, F. Hiromi, U. Masauki, Fundamental study on the sound absorption characteristics of porous concrete by impedance tube, Proc. Jpn. Concr. Inst. 19 (1) (1997) 679–684.

[5] Ministry of Environment of Korea, The Status of Waste Generation and Treatment in 2001.

[6] Eco-Concrete Research Committee, Report of the eco-concrete, Japan Concr. Inst, Tokyo, 1995.

[7] Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes: Part 1. Method Using Standing Wave Ratio, KS F 2814–2831.

[8] M. Tamai, M. Tanaka, Sound absorbing property of porous concrete using Shirasu pumice, Trans. Jpn. Concr. Inst. 16 (1994) 81–88.

[9] Acoustics-Measurement of Sound Absorption in a Reverberation Room, ISO 354.

[10] Method for Measurement of Sound Absorption Coefficients in a Reverberation Room, KS F 2805.

[11] N. Takao, J. Xuemei, M. Isao, J. Rihong, About the sound absorption characteristics of porous concrete, Symposium on the Design and Construction Method of Porous Concrete and Examples of its Recent Application, Japan Concr. Inst, Tokyo, 2002, pp. 127–132.

[12] N. Takao, J. Xuemei, M. Isao, S. Shigeo, The influence on the sound absorption ability by the aggregate size and void ratio of porous concrete about the sound absorption characteristics of porous concrete, Proc. Jpn. Concr. Inst. 23 (1) (2001) 163–168.