- Technical Paper –

AIR VOID CHARACTERISTICS OF CONCRETE WITH DIFFERENT MIX PROPORTIONS AND EXECUTION ON RC SLAB

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ABSTRACT

In order to attain frost resistance of concrete structures, the air void system in hardened concrete has an important role. As a target of RC slab in this study, the air void characteristics of concrete were investigated with the different mix proportions and the execution conditions on actual construction. From these results, it was shown that the air void frequency increase with water-binder ratio decrease, especially the diameter 0-200μm. Confirming the range of air void 0-200μm was one of the significant factors of featuring the distribution of air void and the spacing factor.

Keywords: air void frequency, air content, distribution characteristics, spacing factor

1. INTRODUCTION

The deteriorations of concrete due to severe environment and climate are the major problems affecting long-term durability of concrete structure. Many researches have been conducted to improve durability of concrete nearly a century, such as de-icing salt scaling resistance, corrosion of reinforcement due to freezing-thawing action, chloride ion penetration, alkali silica reaction and so on [1,2]. However, it would need that the key to attain durability of concrete which is practically treated with the deterioration resistance focusing to an actual concrete structures.

Recently years, air-entraining (AE) agent is commonly utilized to improve freeze-thaw resistance of concrete. Air voids entrained by AE agent can reduce the water pressure generated by ice formation in cement paste during freeze-thaw cycles [3]. Therefore, air voids in concrete play an important role in protecting structure from frost damage. Especially, the distribution characteristics and the spacing factor of air void are important factors in order to make durable concrete structures. Promentilla et al. [4] found that the number of air void increase in the range between 20 and 200μm for mortars with AE agent. Referring to the suggestions of Pigeon [5] and Powers [6], smaller spacing factor of air void is one of the factors to improve the frost resistance of concrete. Yuan et al. [7] found that the mass loss of concrete decreases with the average air void diameter and the spacing factor decreases. Almost studies have tended to conduct targeting on the relationship between the air voids and frost resistance of concrete in laboratory. Research on the distribution characteristics and spacing factor of air void of concrete with the multiple mix proportions and the construction conditions on site were also relatively few.

On the other hand, in Tohoku region, it has been promoted the construction project of infrastructures after the great east Japan earthquake and tsunami disaster in 2011. Lifetime improvement of these concrete structures is most important problem to reduce the future maintenance costs. For that reason, the Tohoku Regional development bureau has published the manual for counterplan to frost damage of concrete structures under spreading de-icing salt [8]. This manual was proposed increase of the target air content at loading of freshly mixed concrete on site. That is to cover decreasing of air content while the execution process of construction and to attain air content in hardened concrete. In case of concrete structures under most severe environment on frost damage risk, the W/B less than 45% and the target air content of 6% were requested. Therefore, the investigation of properties of air void in construction stage would be significant.

In this paper, the influences of mixture proportions, the vibration time and the pumping process of concrete on the distribution characteristics of air void were studied in laboratory and construction site of RC slab. Moreover, the relationship between spacing factor and air void frequency in different diameter ranges was discussed.

2. TEST PROGRAMS

2.1 Materials and mix proportion

The mix proportions of concrete are shown in Table 1. In these mixture proportions of concrete, 3 types of cements (Ordinary Portland cement (N: density is 3.16g/cm^3), Fly ash cement (FB: density is 2.96g/cm^3), Blast furnace slag cement (BB: density is 3.04g/cm^3)), four kinds of water-binder ratios (50%, 45%, 40%, 35%) were used. The target of air content and slump of

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Table 1 Mix proportions of concrete

Mixture type	Cement type	W/B (%)	s/a (%)	Unit content: kg/m^3					
				Water	Cement	Fine aggregate	Coarse aggregate	Expansive additive	AE agent
N50	N	50	43.3	170	320	740	1102	20	3.06
N35	N	35	34.4	170	466	547	1187	20	7.78
FB50	FB	50	42.9	168	316	730	1102	20	3.02
FB35	FB	35	33.7	168	460	531	1187	20	7.20
BB50	BB	50	42.9	170	320	730	1102	20	3.06
BB40	BB	40	37.7	170	405	614	1151	20	4.25
BB35	BB	35	33.7	170	466	531	1187	20	7.29

※N, FB, BB are cement types and 50, 45, 40, 35 are water-binder ratios.

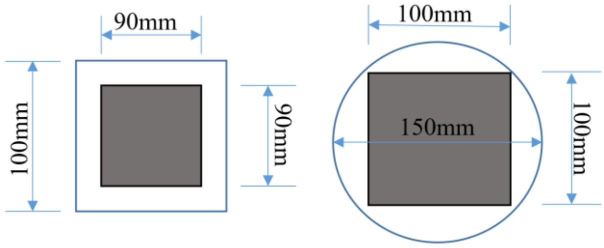


Fig.1 Size of samples for observation of air void

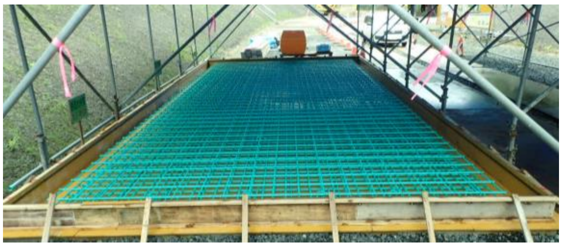


Fig.2 RC mock slab specimen

Table 2 Parameters of air void in laboratory

Parameters	N50	N35	FB50	FB35	BB50	BB40	BB35
Paste content [%]	27.79	32.43	28.07	32.92	28.16	30.96	32.96
Total length of traverse [mm]	2700	2700	2700	2700	2700	2700	2700
Total number of air voids	1296	1450	1134	1470	1146	852	1446
Air content of fresh concrete [%]	6.6	6.3	6.4	7.1	7.0	6.2	7.0
Air content of hardened concrete [%]	7.3	6.6	4.7	7.0	6.4	5.8	7.8
Air content in diameter less than 500μm [%]	5.1	3.8	4.0	5.3	4.5	3.8	6.1
Air content in diameter less than 200μm [%]	2.1	2.4	2.1	2.5	1.9	1.4	2.7
Spacing factor [μm]	138	111	132	130	147	188	143

concrete were 6 ± 1.0% and 12 ± 2.5 cm, were adjusted by air-entraining (AE) agent and superplasticizer, respectively. The maximum size of coarse aggregate was 25mm. The fine aggregates and the coarse aggregates used in the test were pit sand and crushed stone, respectively. Expansive additive was also used in order to reduce cracks.

2.2 Method

(1) Specimens

Two types of concrete specimens were used in this study (Fig.1). One was prism specimen (Size: 100 × 100 × 400mm) that was casted in laboratory and in actual construction site of RC slab of bridge. Another is cylindrical core (Size: ϕ 150 × 200mm) sampled from RC mock slab specimen (Size: 5 × 10.5 × 0.2m, Fig.2). The influence of concrete vibration (5sec, 10sec, 15sec) on air void was surveyed with RC mock slab specimen, the influence of pumping of concrete was also surveyed with sampling specimens on actual construction site. The RC mock slab specimen was produced in Towada area of Aomori prefecture (2018.7), and after the RC slab of bridge was also constructed in that same place (2018.7). The mix proportion on site was adopted the concrete of BB40. Wet curing for 1 month is adopted in all specimens and actual construction.

(2) Testing the air void of concrete

The method of testing the air void of concrete was according to ASTM standard C457 that is procedure A (Linear Traverse Method) [9]. The total number of air void, the air content of hardened concrete, the spacing factor, the total length of traverse and the paste content are shown in Table 2 and Table 3, and the formula for calculating the spacing factor ($\bar{L}$) is presented in Eq. (1).

The air void of concrete was observed with different length of traverse. Therefore, using the air void frequency instead of number of air void to feature the distribution characteristics of air void in hardened concrete. The air void frequency can reflect as the number of air void on the unit traverse length (m), the air void frequency increase with the number of air void increase. The formula for calculating the void frequency (n) is presented in Eq. (2).

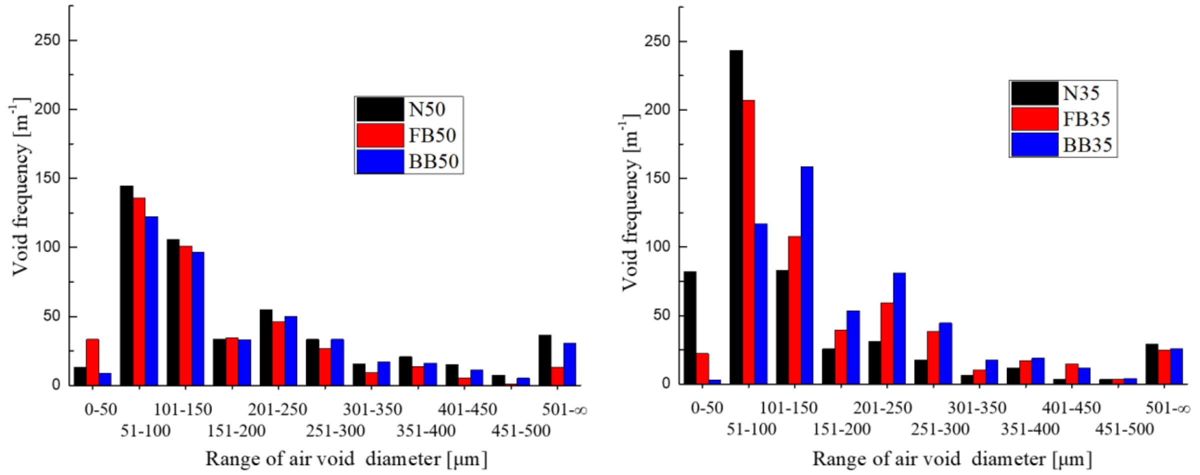
$$\bar{L} = \frac{3}{\alpha}\left[1.4\left(1+\frac{P}{A}\right)^{\frac{1}{3}} - 1\right] \tag{1}$$

where,
$\bar{L}$: Spacing factor (μm)
α : Specific surface (μm^2/μm^3)
P/A : Paste-air ratio

$$\text{Void Frequency (n)} = \frac{N}{T_t} \tag{2}$$

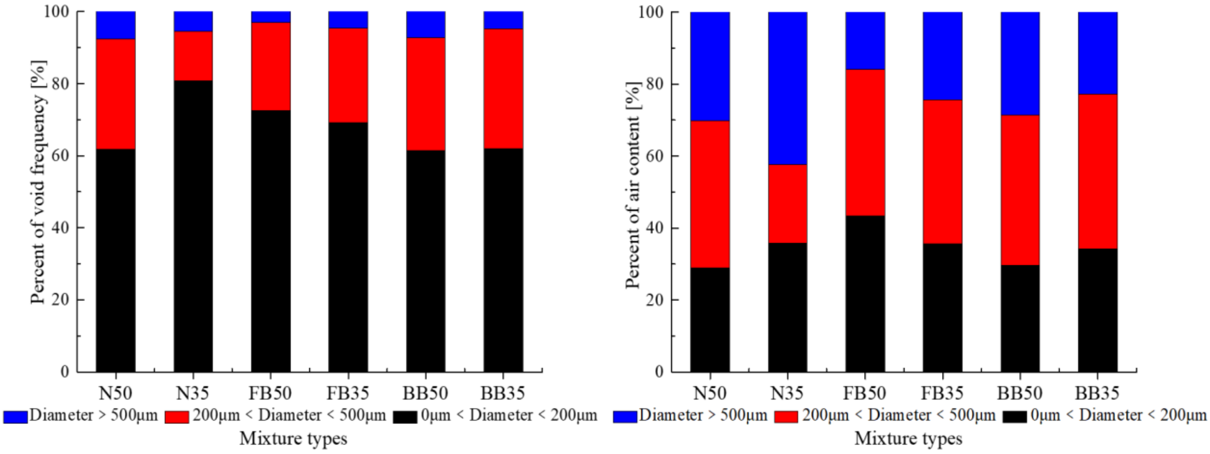
where,
N : Total number of air voids
T_t : Total length of traverse (m)

3. RESULTS AND DISCUSSIONS



a Water-binder ratio 50%　　b Water-binder ratio 35%

Fig.3 Distribution characteristics of air void



a Distribution of percent of void frequency　　b Distribution of percent of air content

Fig.4 Measurement of laboratory

3.1 Distribution characteristics of air void

Air void parameters of specimens made in laboratory are presented in Table 2. Air content of fresh concrete is in the target air content range, but in case of the concrete of FB50, the air content of hardened concrete have great decrease, it may be due to the lower retention of air void in fresh concrete. There is no clear correlation between the air content in fresh and the number of air void in hardened concrete. Comparing the air content of hardened concrete in three different diameter ranges, it is confirmed that in the case of air content of diameter less than 200μm, the air content increase with water-binder ratio decrease except the concrete of BB40. The part of air content of hardened concrete increased than that of fresh concrete. It may be including the sampling error due to limited measurement of the fresh concrete.

The distribution of air void frequency with 6 mix proportions are shown in Fig.3. It is noticed that a large number of air void frequency was presented in the range of diameter 51-300μm than other diameter. Especially in the fine air voids, the air void frequency of W/B 35% are greater than that of W/B 50%, regardless of different cement type. This reason is believe to be due to the retention of air void in fresh concrete, it would depend on increasing viscosity of concrete as unit powder content (W/B), and on the dosage of AE agent. Simultaneously, while the air void frequency gradually decrease with the range of diameter from 50μm to 500μm increase. However, the range of the diameter 0-50μm and greater than 500μm were different from the previous trend. When the ranges of diameter is 0-50μm and greater than 500μm, these have fewer air void frequency. In case of the range of diameter greater than 500μm, the concretes with fly ash (FB) have fewer air void frequency than other two cement types (N, BB). It would be because of unit content of powder material and fine aggregates.

From Fig.3, it is confirmed that the air void distribution in hardened concrete would be composed from three part with formation like an arch shape. The range of diameter 0-200μm is fine part that may be air entraining by AE agent. The range of diameter greater than 500μm is large part that may be forming by entrapped air during mixing of concrete. The range of diameter 201-500μm is middle part that may be combining the entrained air and the entrapped air. Then, the air void characteristics of concrete could be considered from the viewpoint of these three part given within a distribution.

Table 3 Parameters of air void on site

Parameters	Mock slab				Actual construction site		
	After pumping	Vibration 5s	Vibration 10s	Vibration 15s	Before pumping	After pumping	After Vibration
Paste content [%]	31	31	31	31	30.96	30.96	30.96
Total length of traverse [mm]	2700	3300	3300	3300	2700	2700	2700
Total number of air voids	1439	1604	1242	1295	1402	1492	1536
Air content of fresh concrete [%]	6.4	5.8	4.3	5.4	6.0	—	—
Air content of hardened concrete [%]	6.6	6.7	6.3	6.9	5.1	5.1	6.4
Air content in diameter less than 500μm [%]	5.3	5.1	4.4	4.7	3.8	4.1	4.8
Air content in diameter less than 200μm [%]	2.9	2.5	1.7	1.8	2.5	2.6	2.9
Spacing factor [μm]	128	139	174	172	109	106	114

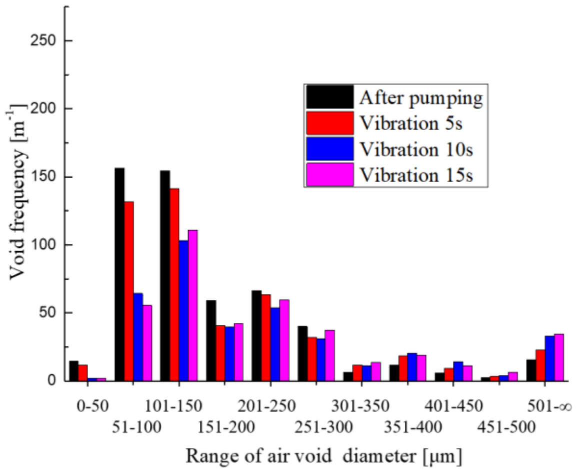
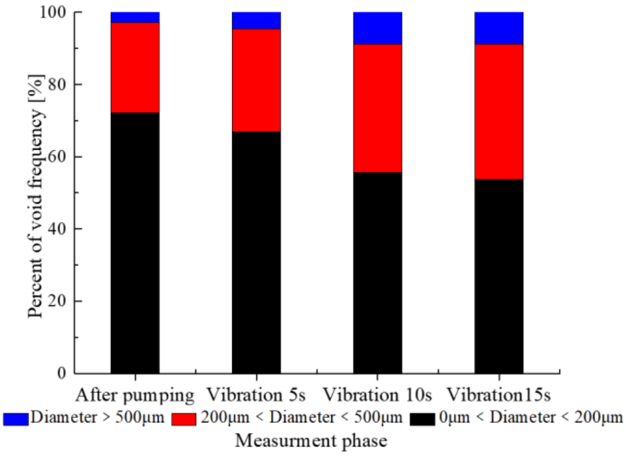
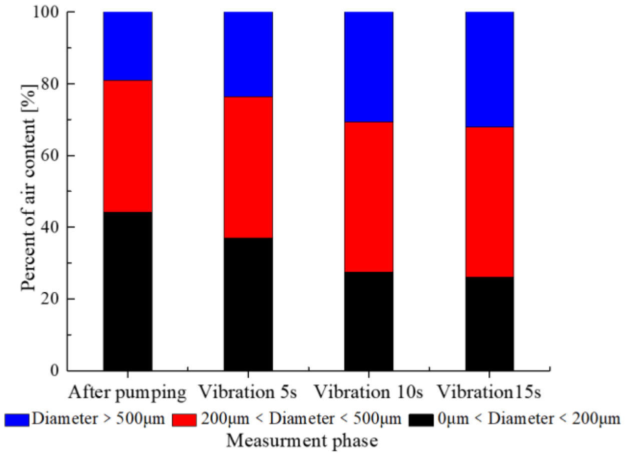


Fig.5 Distribution characteristics (mock slab)



a Distribution of percent of void frequency



b Distribution of percent of air content

Fig.6 Measurement of mock slab

3.2 Air void frequency and air content of concrete made in laboratory and construction site

(1) Measurement on laboratory specimen

The relationships in diameter range with the percent of air void frequency and the percent of air content are shown in Fig.4. From these figures, the percent of air void frequency and the percent of air content are divided into three parts by diameter range that include 0-200μm, 201-500μm and greater than 500μm. It can be noticed that in case of the range of diameter 201-500μm and greater than 500μm, the percent of air content was greater, but the percent of air void frequency was less. On the other side, in case of the range of diameter 0-200μm which is entrained by AE agent, is contrary to the above results, and the percent of air void frequency was greater than that of air content. Moreover, the percent of air void frequency in the diameter 0-200μm is greater than 50%, compare to the range of other diameter. In case of N35, the percent of frequency of fine air voids is most large. This reason would depend on dosage of AE agent. From these results, the value of fine air void frequency than that of air content will be promising as important key to evaluate the effect of air entrainment.

(2) Measurement on RC mock slab specimen

Parameters of air void on RC mock slab specimen with different vibrating time of concrete, are presented in Table 3. Air content of fresh concrete is in the target air content range. The air content of hardened concrete tends to decrease with the increase of vibration time in RC mock slab.

The concrete of BB40 was used on RC mock slab specimen. Influence of vibration time on distribution of air void frequency in hardened concrete are shown in Fig.5. It can be noticed while the fine diameter 0-200μm, the air void frequency tends to decrease with vibration time increase. While the diameter greater than 300μm, the air void frequency increase with vibration time increase, especially in the diameter greater than 450μm. The reason of this result that the many fine air voids may develop into larger voids with vibration time increase.

Fig.6 shows the characteristics distribution of percent of air void in certain range. For these two figures, in case of the diameter 0-200μm, the percent of air content and the percent of air void frequency decrease with vibration time increase. It is consistent with the above conclusion. While the vibration of 15s, the percent of air void frequency decrease in about 20%.

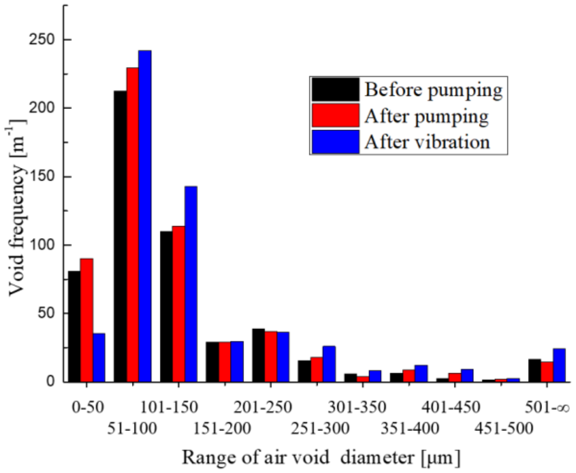
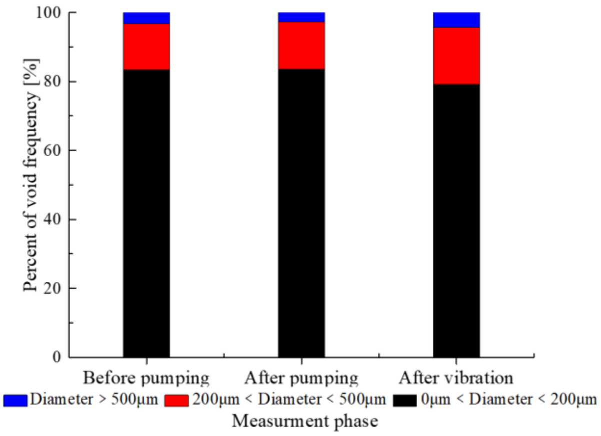
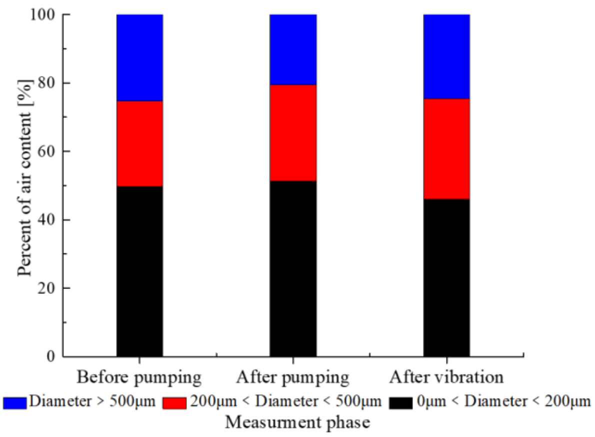


Fig.7 Distribution characteristics (actual construction)



a Distribution of percent of void frequency



b Distribution of percent of air content

Fig.8 Measurement of actual construction

(3) Measurement on specimen made in actual construction stage

Parameters of air void on specimen made in construction stage, are also presented in Table 3. Air content of fresh concrete is in the target air content range. Significant decrease of the air content in hardened concrete was confirmed with the pumping process in actual construction.

The vibration time of 8s was used on compacting

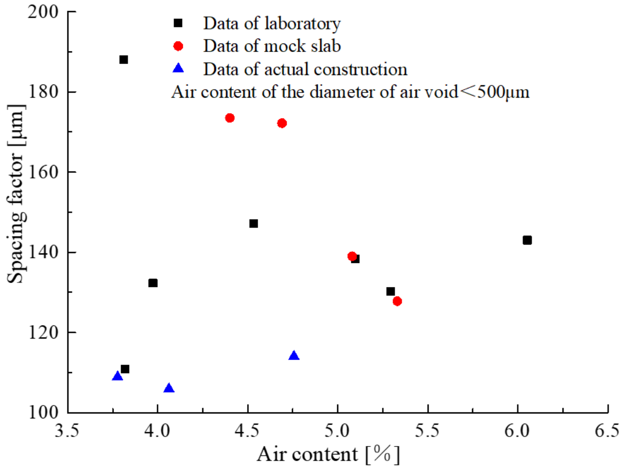


Fig.9 Air content of the diameter 0-500μm

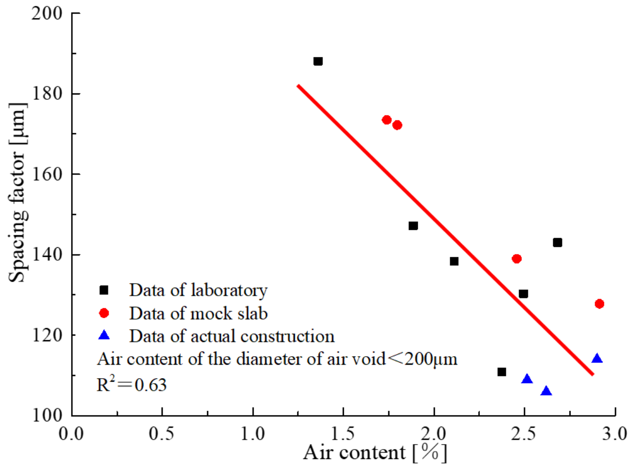


Fig.10 Air content of the diameter 0-200μm

concrete in the actual construction. Influence of before pumping, after pumping and after compacting on distribution of the air void in hardened concrete were shown in Fig.7 and Fig.8. It can be indicated when the range is in diameter 0-200μm, changing of the percent of air void frequency and the percent of air content with the process of pumping concrete is few (see Fig.8 (a), (b)). Because, the pumping height is relatively short, and the vibration time is not excessive.

3.3 Relationships in spacing factor with air content and air void frequency

Relationships in the spacing factor with the air content and the air void frequency are shown in Fig.9-12. The data of laboratory, the data of RC mock slab specimen and the data of actual construction are contained in these 4 figures. From Fig.9, it can be noticed that between the spacing factor and the air content in the range of diameter 0-500μm is not correlation. Fig.10-12 are shown that the spacing factor decrease with the air void frequency and air content increase. The spacing factor fits better with the air void frequency than with the air content in linear condition. Especially, while the range of diameter 0-200μm, the correlation coefficient of the regression curve was 0.94. This result is illustrated that the spacing factor can be reflected indirectly through the number of air void,

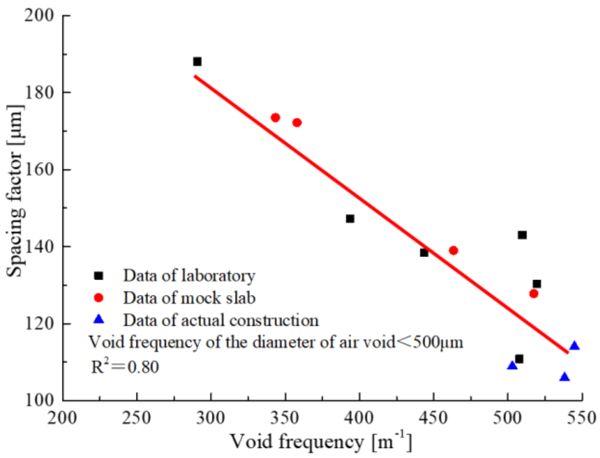


Fig.11 Void frequency of the diameter 0-500μm

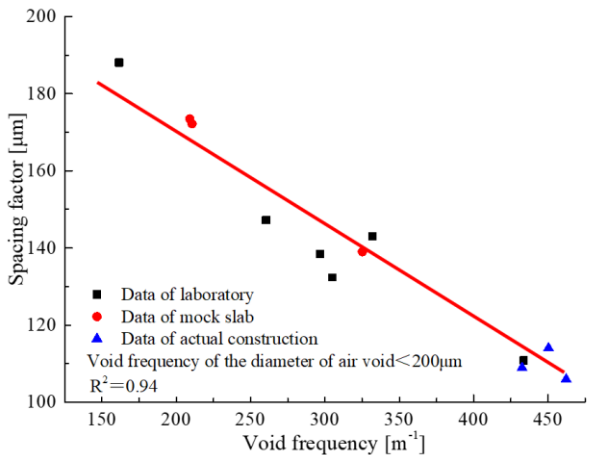


Fig.12 Void frequency of the diameter 0-200μm

regardless of different mix proportions and execution on RC slab. Simultaneously, this result is consistent with the results of section 3.2 that the air void frequency greater than 50% in the range of diameter 0-200μm. Therefore, the diameter less than 200μm is one of the significant factors to evaluate the distribution of air void and the spacing factor. The specific surface (α) in spacing factor Eq. (1) is greatly influenced by the number of air void, and the spacing factor may be characterized by the void frequency regardless of mix proportions and execution on site. Air void characteristics in cement matrix would be featured depending its random property.

4. CONCLUSIONS

In this investigation, the aim was to study the distribution characteristics of air void of hardened concrete with different mix proportions and execution on RC slab. The following conclusions may be drawn:

(1) By comparing the distribution characteristics of air void of hardened concrete with different mix proportions, it is confirmed that a large number of air void was presented in the diameter of 50-300μm. Especially in the fine air voids, the air void frequency of W/B 35% are greater than that of W/B 50%, regardless of different cement type. It would depend on retention of air void due to increasing viscosity of concrete as unit powder content (W/B), and on the dosage of AE agent.

(2) In case of the range of diameter 0-200μm which is entrained by AE agent, the percent of air void frequency was greater than 50%, compare to the range of other diameter, with different mixture proportion and execution on slab. From these results, the value of fine air void frequency than that of air content will be promising as important key to evaluate the effect of air entrainment.

(3) Excessive vibration is lowered the quality of air void as the range of diameter 0-200μm. However, influence of pumping process is relatively small.

(4) The spacing factor fits better with the air void frequency than with the air content in linear condition. Especially, while the range of diameter 0-200μm, the correlation coefficient of the regression curve is 0.94. This result is illustrated that the spacing factor can be reflected indirectly through the number of air void, regardless of different mix proportions and execution on RC slab. In addition, the diameter less than 200μm is one of the significant factors to evaluate the distribution of air void and the spacing factor.

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