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STUDY OF MIX PROPORTION AND QUALITY CONTROL OF POROUS CONCRETE PAVEMENT USED ON URBAN EXPRESSWAY TUNNEL

Yoshihiko TAKADA[1*], Eisaku NAKAYAMA[1] and Takeshi SUZUKI[1]

[1]*Hanshin Expressway company limited ,Osaka, JAPAN*
[*] *yoshihiko-takada@hanshin-exp.co.jp*

ABSTRACT

As a traffic safety measures, Porous concrete (POC) pavement was adopted around the entrances of Shorenjigawa tunnel in Yodogawasagan-Route in Hanshin Expressway. However, it is the first time that POC pavement was used such a heavy traffic route in the world. It is required to have sufficient performances such as strength, durability and skid resistance. Comparative studies were conducted changing mix proportion included water-binder ratio and aggregates types. As a result of this study, changing mix proportion leads strength and durability of POC and aggregate type affects skid resistance on the surface of POC pavement. POC using the mix design obtained in this examination satisfied the required level of flexural strength and permeability. Aggregate type was selected in consideration of flexural strength, drying shrinkage and skid resistance comprehensively.

Keywords. porous concrete pavement, water-binder ratio, aggregate, skid resistance, fine sand

1. INTRODUCTION

The 1st phase of Yodogawasagan Route in Hanshin expressway network is constructed in Osaka urban city area as a part of the Second Ring Road, and has opened to traffic on May 25, 2013. 77% of this route (about 3.6km) is composed of cut and cover tunnels and concrete pavement is adopted in tunnel sections, reducing construction and maintenance cost. Fig.1 shows pavement structures in the cut and cover tunnel section. Longitudinal slope around the entrance of the tunnel is 5%, therefore it is expected that vehicles enter at considerably high speed.

In addition, the S-shaped sharp curve near the entrance may cause accidents, especially on moist surface of pavements in the rain.   In order to eliminate stagnant rainwater and prevent vehicles from slipping, an application of porous concrete (POC) around the entrance of the tunnel was highly recommended.

Since the development of POC 10 years ago, it has been applied several types of pavement structures, due to its high property with 15-20% and high flexural strength. However, it was first time that POC was going to be applied for construction of a large area in such a heavy traffic route in the world. Therefore, the POC needed to have sufficient properties of strength, durability and skid resistance. The most important function of porous concrete is to secure adequate porosity so that water can readily pass through pavement.

This paper will focus on evaluations of porous concrete about the performance of this material, designs and construction techniques. Mix proportion including water-binder ratio and aggregate types are the important factors to determine strength and durability of POC. Changing aggregate types contributes to an increased skid resistance of POC pavement.

In this study, various mix designs were examined to select constituents that are available for Yodogawasagan Route. Parametric studies including effects of water-binder ratio and aggregates types were carried out. Following that, experimental studies were performed to evaluate flexure strength, compressive strength, hydraulic conductivity, drying shrinkage, and skid resistance. Finally, recommended mix designs for POC including water-binder ratio and aggregate types were determined.

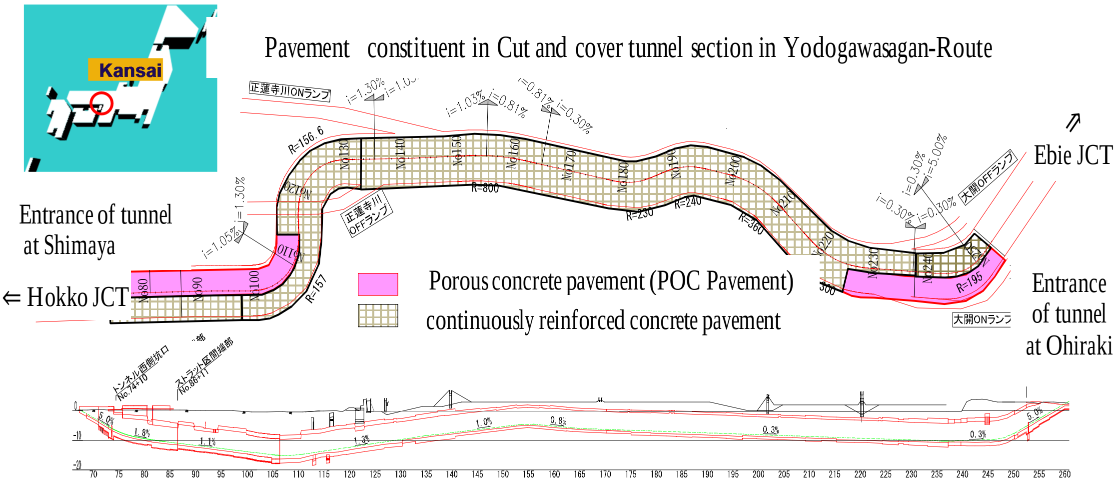
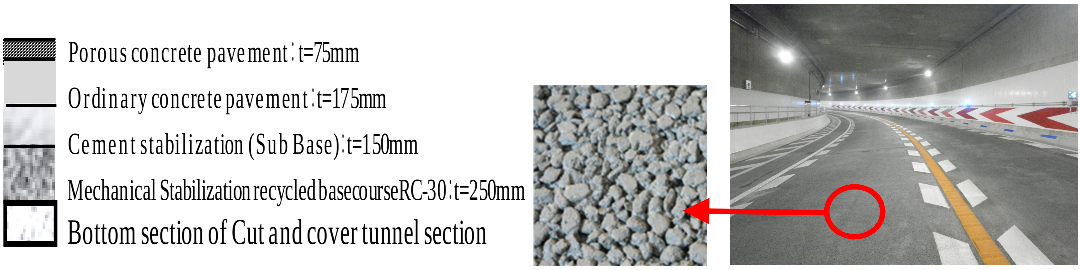


Fig. 1 Pavement structures in cut and cover tunnel section in Yodogawasagan-Route

2. OVERVIEW OF POROUS CONCRETE PAVEMENT

POC pavement applied in this project is a hybrid structure consisting of POC and ordinary concrete, as shown in fig-2. POC with a thickness of 75 ㎜ is bonded with an ordinary concrete pavement with a thickness of 175 ㎜ to act as a functional layer on the slab. POC and ordinary concrete are adhered to shrinkage compensating mortar.



POC pavement section Surface of the POC pavement

Fig. 2 POC pavement in cut and cover tunnel

3. MIX PROPORTION

(1) Process of design mixture

In order to construct POC pavement it was required to have almost the same durability as ordinary concrete pavement, with porosity of about 15 to 20%. Thus, the mix design was performed to attain the target properties as shown in Table 1.

The water-binder ratio of POC was recommended to 25% or 22.5% based on a prior research. Binder includes cement and special admixture. Admixtures such as a high-range water reducer and viscosity modifying admixture had insignificant effects on the flexure strength, hydraulic conductivity and workability of the porous concrete mixes examined. The target void content of POC was prepared to 17%. The proportion mix of POC used in this project was developed in the processes in fig 3. In order to determine a mix proportion, parametric studies including lab tests and field trials were carried out. This paper focuses on the lab tests (1) and (2) which were especially considered to affect the quality of POC.

Table 1 Target properties of POC

Item	Target value
Porosity	15 to 20%
Bending strength	4.5N/mm2
Coefficient of permeability	10^{-2} cm/sec and more
Amount of aggregate loss by Cantabro test	Less than 20%
The length change rate by drying shrinkage	From 800μ to 1200 μ in six months

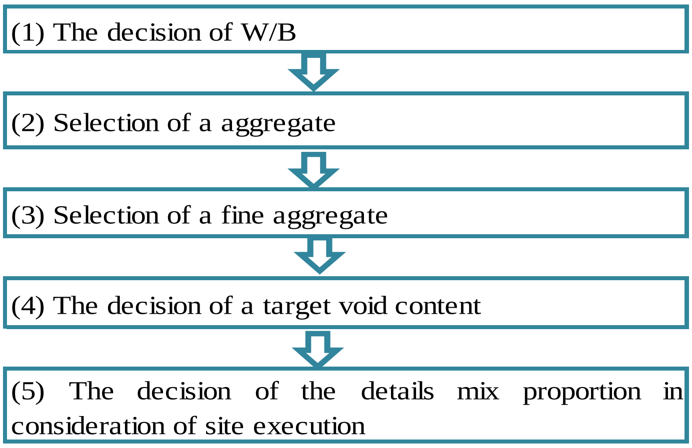


Fig.3 Process of mix design for POC

(2) Variety of aggregate types

Three kinds of aggregate which can be supplied to paving work were selected for prior research. The aggregate was made of rocks which were easy to procure, including hard sandstone produced from Hiroshima Prefecture, hard sandstone from Wakayama Prefecture, and quartz andesite from Hyogo Prefecture. The hard sandstone has been utilized as crusher-run stone for pavement. The quartz andesite has been used as crusher-run stone for concretes. Approximately 10% to 11% of wear loss in weight were found on all the aggregates in Los Abrasion test, which indicated high resistance to wear loss.

In prior research, the maximum size of the aggregate of POC was determined to be 13 mm or 15 mm. In contrast, the hard sandstone from Hiroshima whose maximum size was 20 mm was also examined. Physical properties of aggregate are shown in Table-2. In addition to Los Angeles Abrasion test, Mohs hardness was measured to evaluate wear loss resistance after polishing by mirror finish at the same level as sample for electronic micro analysis method (EPMA). Mohs hardness measured by Mohs hardness meter was 5.5 in hard sandstone and 6.5 in quartz andesite, which is harder compared to 2.5 in limestone As a consequence, the aggregate used for mix of POC had high wear loss resistance.

Table 2 Physical properties of aggregates

Aggregate type	Hard sandstones		Hard sandstones	Quartzs andesite
Locality	Hiroshimaha Pre.(HS)		Wakayama Pre.(WS)	Hyogo Pre.(HD)
Agg.size(mm)	20	13	13	15
Specific gravity（g/cm^3)	2.73	2.73	2.68	2.62
Alkali silica reaction	Harmlessness			
Wear loss in weights(%)	-	11.3	11.5	10.4
Mohs hardness	-	5.5	5.5	6.5

(4) Mix proportion

Table-3 shows the recommended mix proportion. The raw materials for POC included water, cement special admixture, fine sand, and aggregate between 10 and 13 mm in top size. In general, decreased water content yielded a higher density and higher flexure strength, and reduced hydraulic conductivity. As for POC using Gmax13mm of aggregate, a high skid resistivity in early traffic was confirmed. The ordinary Portland cement was used. The fine sand consisted of crusher sand and mixed sand which was the mixture of sea sand and blast-furnace slag fine aggregate. The fineness modulus of the fine sand was prepared 2.93. Special admixture for POC was used by inorganic system. In the mix of W/B22.5%, in order to acquire a fresh character, the highly efficient water reducing agent was added. Finally, The mix proportion of each aggregate were prepared with density of compaction of 100±5% according to *consistency test method by vibration compaction method.*

Table 3 POC Mix design

MIX No	Type of Aggregate	Top size (mm)	W/B (%)	Porosity (%)	Vs/Vm (%)	Vm/Vg (%)	Unit Cobtent(kg/m^3)							Ad (C×%)
							W	C	P	S1	S2	G1	G2	
HS25	Hard sandstones from Hiroshima Pre.	13	25.0	17.0	24.0	51.5	94	355	20	73	106	1490	0	0
HS25 (20)	Hard sandstones from Hiroshima Pre.	20			26.0	44.0	82	308	20	71	103	627	944	0
WS25	Hard sandstones from Wakayama Pre.	13			26.0	52.0	92	348	20	79	116	1463	0	0
HD25	Quartzs andesite from Hyogo Pre.	15			20.0	48.5	95	360	20	58	85	1464	0	0
HS22.5	Hard sandstones from Hiroshima Pre.	13	22.5		28.0	54.0	86	358	25	88	128	1466	0	0.35
WS22.5	Hard sandstones from Wakayama Pre.	13			28.0	55.0	87	362	25	89	129	1435	0	0.075
HD22.5	Quartzs andesite from Hyogo Pre.	15			24.0	50.0	86	359	25	71	104	1450	0	0.20

※P ; Special admixture, Ad ; Highly efficient water reducing agent

4. LAB TEST

The purpose of lab tests was to evaluate the mechanical and hydraulic characteristics of POC to be used as drainage layer of pavement to obtain better development in terms of skid resistance. Various tests were performed such as flexure strength, compressive strength, hydraulic conductivity, drying shrinkage, and skid resistance to determine the mix designs for POC including water-binder ratio and aggregates type.

(1) Flexure strength test

Flexure strength test shown in fig. 4 was performed using the specimen of 400x100x100 (mm) dimensions based on *JIS A 1106*. The value of flexure strength was set more than 4.5N/mm in 28 days.

(2) Compression strength test and modulus of elasticity measurement

The uniaxial compression test and the modulus of elasticity measurement shown in fig. 5 were performed with the specimen moulded 100x200mm concrete cylinder based on *JIS A 1149.*

Fig. 4 Flexure strength test

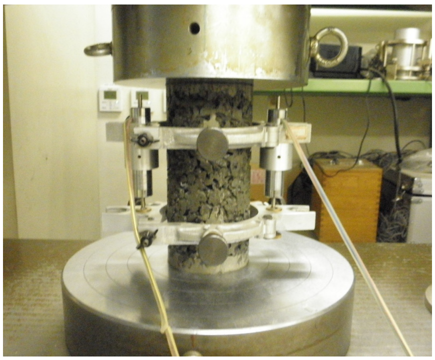


Fig. 5 Compression strength test and modulus of elasticity measurement Flexure strength test

(3) Cantabro test

To confirm fretting resistance of aggregate, Cantabro test was conducted in accordance with *specifications for Pavement survey test method*. The specimen was moulded 100x63.5mm concrete cylinder, and the amount of aggregate loss was set less than 20% in 28 days.

(4) Constant head permeability test

Constant head permeability test was performed using the specimen moulded 100x100mm concrete cylinder in accordance with *JCI permeability test of porous concrete*. The value of coefficient of permeability was set more than 0.01 cm/s.

(5) Drying shrinkage test

Drying shrinkage test was performed using the specimen of 400x100x100 (mm) dimensions based on *JIS A 1129*. The basis length of the specimen was measured after the water curing in 7days. Then, it was preserved in laboratory with humidity of 60% and temperature of RH20 ℃ , and the length rate of change was measured every 1 month. Based on the concrete standard specification in Japan, the target value of the length change rate was set, ranging from 800 μ to 1200 μ in six months.

(6) ASTM wear test

The ASTM wear test was performed with the testing machine defined by ASTM C 779 shown in fig-6. The abrasion loss was measured on the surface of specimen after wearing with iron powder for 120 minutes. Furthermore, in order to examine the skid resistance underwater, specimens were worn with only abrasion head underwater for 60 minutes. Also, skid resistance on the surface of the specimen was measured by D.F. Tester. The D.F. Tester is an instrument which can determine the physical properties needed by different industries as it can measure coefficient of friction under various conditions. It reports the friction as a function of speed from 0 to 80 km/h at a contact pressure similar to that of typical motor vehicles although it is small in size.

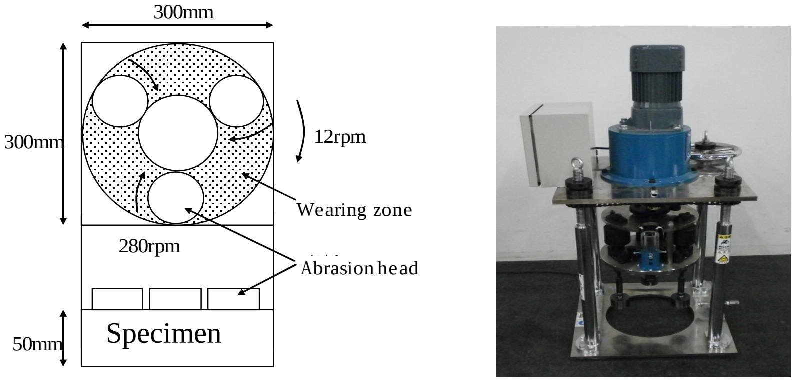


Fig. 6 Outline of ASTM wear test

5. TEST RESULT

(1) Flexure strength test

Flexure test results and specimens after test are shown in fig.7. The value of flexure strength of all the mixes exceeds 4.5N/mm^2 of the target value in 28 days. All the mixes excepted hard sandstone from Hiroshima (HS25) showed high strength, exceeding more than 5.0N/mm^2. There is not tremendous difference between aggregate. In the picture of specimens after flexure strength test, failure is observed between the cement-aggregate interface and could be characterized as bending tension.

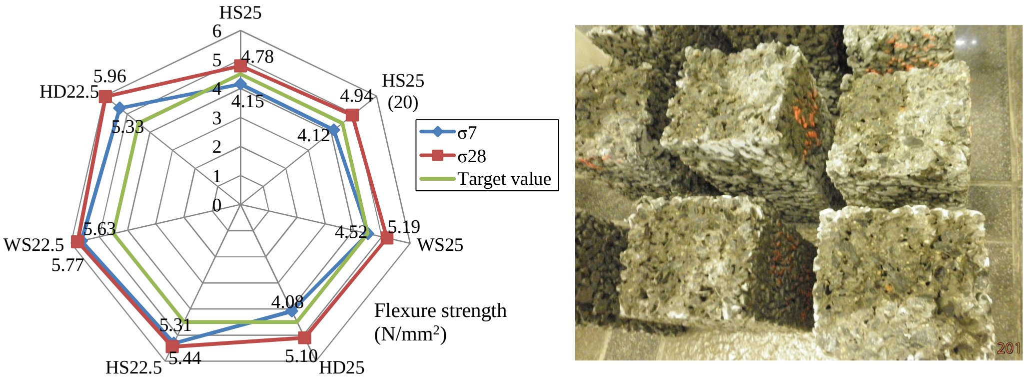
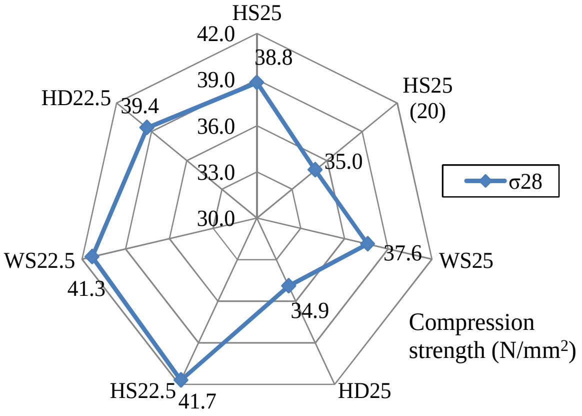


Fig. 7 Result of flexure strength test

(2) Compression strength test and modulus-of-elasticity measurement

The results of the 28-day compressive strength tests and modulus of elasticity for all the mixes designs are summarized in fig.8 and fig.9 respectively. In fig 8, the number of compressive strength ranged from about 39 MPa to 42MPa with W/B22.5% and about 35 MPa to 39MPa with W/B25% respectively. There was not a tremendous difference between aggregate. In fig.9 the modulus of elasticity ranges from approximately 27 to 32 kN/mm2, which was almost the same as ordinary concrete.



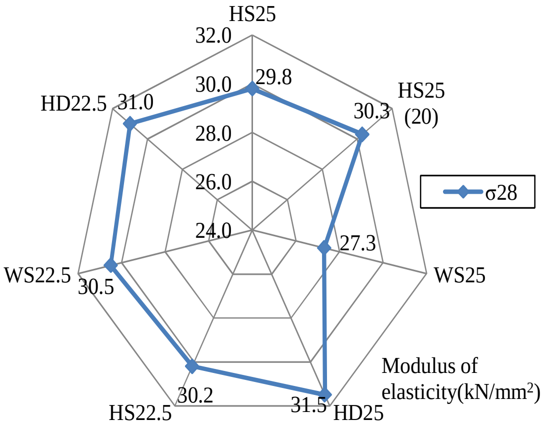


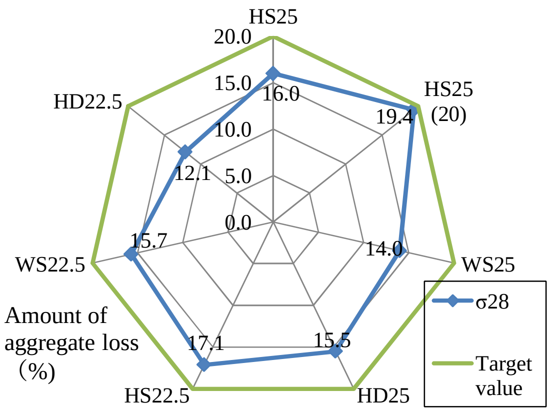
Fig. 8 Result of compressive strength test **Fig.9 Result of Modulus of elasticity**

(3) Cantabro test

Result of Cantabro test is shown in fig-10. All the mixes meet the wastage rate of 20% as the target value. As for the 25% W/B mix, hard sandstone from Wakayama indicated the least amount of loss. Between 25% W/B mix and 22.5% W/B mix, there was not a huge difference in the amount of loss.

(4) Permeability test

Fig.11 shows permeability test result. Coefficient of permeability of all the mixes resulted in far exceeding the target value of 0.01 cm/s. Coefficients of permeability did not have a large difference between mix designs.



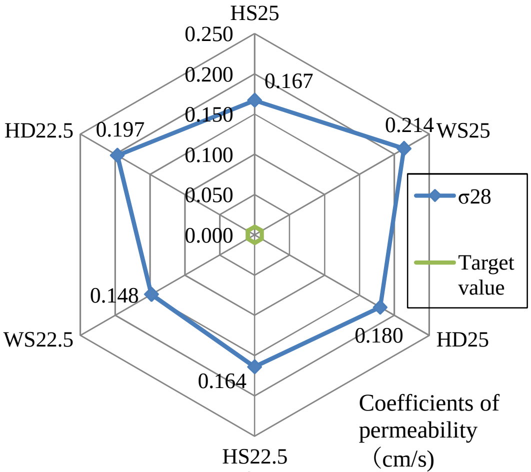


Fig. 10 Result of Cantabro test **Fig. 11 Results of Permeability test**

(5) Drying shrinkage

Fig.12 presents the length change rate in drying shrinkage test for the period of six months. The length change rate of mix of quartz andesite (HD W/B22.5 and HD W/B25) was approximately 500 μ, which was larger than others. In contrast, that of other mix showed smaller number ranging from 300 μ to 400 μ After three months, the length change rate remained stable in whole. Consequently, it is obvious that the ratio remained stable after six months.

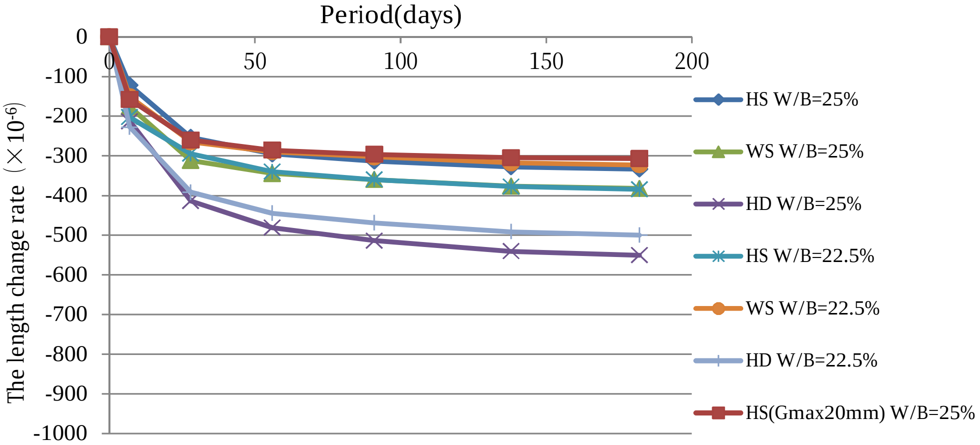
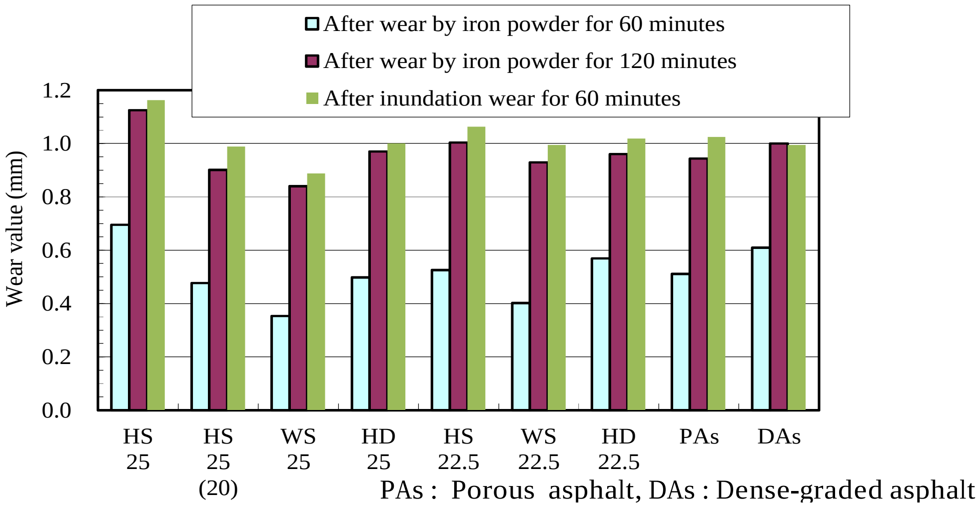


Fig. 12 Result of the Drying shrinkage

(6) ASTM wear test

a) Abrasion loss

Fig-13 presents abrasion loss measurement results in ASTM wear test. After wearing with iron powder for 120 minutes, hard sandstone (WS25) showed the lowest wear value while Hard sandstone from Hyogo (HS25) is the largest. The same trend was observed in ASTM wear test underwater for 60 minutes. All the mixes of POC except HS25 tended to show lower wear value than asphalt mixture. Thus, changes in the water-binder ratio also did not contribute to abrasion loss.



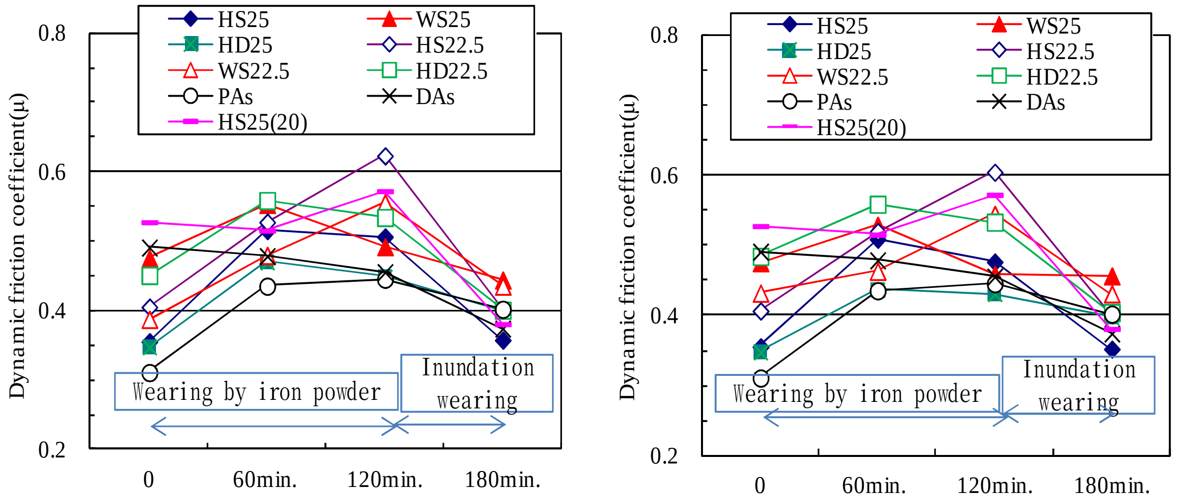
PAs : Porous asphalt, DAs : Dense-graded asphalt

Fig.13 Result of the abrasion loss measurement in ASTM wear test

b) Skid resistivity by dynamic friction tester

After ASTM wear test, DF Tester was performed to measure the dynamic friction coefficient on the surface of specimens. Fig.14 presents dynamic friction at 60km/h and 80km/h, respectively. After wearing test with iron powder, dynamic friction coefficient tended to increase, because wearing with iron powder around some aggregate made the surface of aggregate rough. On the other hand, after wearing test with iron powder underwater, dynamic friction coefficient tended to decrease since wearing test underwater made the surface of aggregate smooth.

After ASTM wear test, it was found that the mortar covering aggregate was peeled, exposing some parts of aggregate. In comparison with the results before and after ASTM wear test, dynamic friction coefficient was not observed great difference. The mortar coating aggregate may not contribute to the change of skid resistivity of pavement surface. Compared with all the mixes, the mix of POC using the hard sandstone (WS25) was slightly larger dynamic friction coefficient than asphalt mixture after submersion underwater. That is why the mix by hard sandstone (WS25) showed the lowest wear loss, and remained larger rough-texture on the surface than other mix.



(a) 60km/h **(b) 80km/h**

Fig. 14 Result of dynamic friction coefficient on the surface

6. SUMMARY AND CONCLUSION

In this research, lab tests were conducted to examine various performances about the specification of the porous concrete used on a highway main lane. As a result, the following were found.

(1)The value of flexure strength of all the mixes exceeded 4.5N/mm2 of target value in 28 days depending on the mix design.

(2)Compressive strength yielded a range of values from about 39 MPa to 42MPa with 22.5% of W/B and about 35 MPa to 39MPa with 25% of W/B. The modulus of elasticity was

27 to 32 kN/mm^2, and is almost the same as ordinary concrete. There were not huge differences between the aggregate types.

(3)All the mixes met the target value of wastage rate, 20%.

(4)The coefficient of permeability of all the mixes resulted in greatly exceeding 0.01 cm/s of reference value.

(5)The length change rate for mix of quartz andesite (HD22.5,HD25) was more than 500μ, and was larger than others. On the other hands, that of other mix ranged from 300μ to 400μ and is smaller.

(6)The length change rate of drying shrinkage was obviously influenced more by the aggregate types than the water-binder ratio. All the mixes of POC except HS25 tend to be lower wear value than asphalt mixture. After wearing with iron powder, dynamic friction coefficient tended to increase. On the other hand, after wearing underwater, dynamic friction coefficient tended to decrease.

The results indicate that all the mixes of POC prepared for this study satisfied performance standard on highway. Mix including water-binder ratio and the type of aggregate had some effect on the engineering properties of the porous concrete. Comparison of water-binder ratio, they have a much smaller effect on flexure strength, compressive strength, modulus of elasticity and drying shrinkage. In this study, the mix of W/B25% is recommended because of the small fluctuation on surface water and proven track records. With regard to the comparison of aggregate types, hard sandstone from Wakayama is recommend for an aggregate because it was the most balanced in terms of modulus of rupture, the amount of drying shrinkages, and the slide resistivity.

REFERENCES

ASTM ; C779/C779M-Standard Test Method for Abrasion Resistance of Horizontal Concrete Surfaces, 2010

Japan Cement Association, Technical Report for design and construction of roadway porous concrete pavements, 2007

Japan Road Association, Specifications for Pavement survey test method ,2007

JSCE, Standard Specifications for Concrete Structures-2002 "Structural Performance Verification", 2002

The developed porous concrete pavements and its performance, Satoshi NAGAO, Etsuro NODA, Daiki NAKAHARA, Katsura ENDO, Road Engineering Association of Asia and Australasia Conference, Sep. 2009