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EVALUATION RESULT ON LONG-TERM PERFORMANCE OF INORGANIC REPAIRING MATERIAL FOR CONCRETE CANAL

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Abstract. *Irrigation concrete structure is one of the important infrastructures. Lots of them have been supplied long periods, and some are approaching to the end of designed service life. It is impossible to re-construct all these facilities that exceeded their service life due to the economical and/or social subjects, therefore, we have to try to extend their service life as long as we can. Up to now, various repairing method for these aging concrete canal have been developed in Japan.*

Surface covering technique is one of the most frequent repairing methods for deteriorated concrete canal. The standard for the assurance of various performances such as adhesive strength, deterrence performance against neutralization and climate, durability against abrasion, and so on, have been set and made the regulation well known to engineers in Japan. However, long-term performance and durability of all repairing material have not been confirmed yet in actual structures. Thus, it is necessary to establish the evaluation method as well as to confirm the long-term performance of repairing materials.

In this study, various performances of inorganic material, 8 year ages after repaired on surface of concrete canal, were evaluated experimentally. As a result, neutralization depth was very small on the whole, and the coefficient of neutralization velocity of concrete canal was smaller than that of general concrete structures. Adhesive strength of concrete canal was larger than the regulated values in standard, and destructive form was neither interface or in repairing material, but broke in base concrete. Small abrasion depth was confirmed, but the maximum abraded depth was less than or equal to 1mm. The foregoing results referred that this material had nothing problem after supplying at least 8 years. Moreover, residual life was estimated to be more than 40 years entirely.

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1 INTRODUCTION

Irrigation concrete structures, such as dam, head work, pond and canal, have been improved for the efficient business management of farming in Japan. These infra-structures are well known as important facilities, not only for the water use of agriculture but also for the living environment of rural area, however, they are now facing great difficulties. First of all, many of them had constructed intensively during 1960s to 1970s, the period of rapid economic growth in Japan. Irrigation canal which designed supplying period are set to 40 years are approaching to the limit to renew due to their designed life. Second of all, economic conditions are getting worse gradually in Japan and it is difficult to obtain enough budgets for reconstructing all these facilities even though their service life have finished. And, third of all, some social problems, decline of agriculture, decrement and aging of the population that is employed in agriculture, and so on. These socio and economical problems also affect to the maintenance of irrigation concrete structures.

Ministry of Agriculture, Forestry and Fisheries are going on the introduction of "Stock Management", which is based on the performance based design, and try to use those aging facilities as long as we can without renewing. It is necessary to verify accurately and quantitatively every performance of each facility for exceeding utilization of designed service life. General drawing and specification targeted at reinforced concrete (call "RC" here after) canal, which is main structural type of irrigation canal, have been arranged up to now as the stock amount of RC canal in Japan is so huge; approximately 45 thousands kilometer length for main canal and 400 thousands kilometer length for all canal. As part on the collection of these specifications, construction method for the countermeasure of repairing and reinforcing were discussed, and guideline on them have published in 2013 [1]. In that guideline, additional 20 years durability is required for repairing method/material, and explains the importance of monitoring. However, most of the repairing technique does neither have assurance nor construction record. It is necessary to accumulate further information on actual data through follow-up survey.


Picture 1: Representative concrete canal

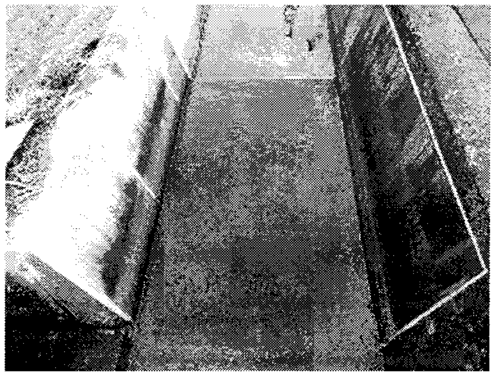
Surface covering technique is one of the most frequent repairing methods for deteriorated RC canal now. This technique is mainly divided into two types of material. One is using inorganic binder such as cement mortar or polymer cement mortar, and the other is using organic binder such as epoxy resin, acrylic resin, and so on. Most of these materials and techniques have developed in the field of sewage repair work. The commonality between sewage canal (mainly pipeline type) and agricultural RC canal (open channel type) is the supplied environment; always contact with water. On the contrary, differentiate points are also concerned to supplied environment; the quality of water and ultraviolet rays. In general, repairing material for sewage should chose the organic binder as the sewage environment sometimes generates very severe conditions; high concentrations of sulfate attack. However, this is not necessarily true, and the most important point for choosing repairing material is the correct evaluation of corrosive condition. It's the essence of performance based design. Considering these things described above, quality standard on repairing method for irrigation RC canal have presented in the guideline quoted above [1]. As an object of repairing method using inorganic binder, various performances such as adhesive strength, deterrence performance against neutralization and climate, durability against abrasion and so on, have been set and made the regulation well known to engineers in Japan.

However, long-term performance and durability of almost all repairing material have not been confirmed yet. Thus, it is necessary to establish the evaluation method as well as to confirm the long-term performance of repairing materials. Then, one kind of repairing material which is considered to common inorganic binder was focused in this research. Various performances of inorganic binder, 8 year ages after repaired on surface of concrete canal, were evaluated experimentally. Furthermore, validity of evaluation and prediction method suggested in guideline was considered.

2 EXPERIMENTAL PROCEDURE

2.1 Polymer cement mortar applied for repairing inorganic material

In this study, one type of polymer cement mortar (called PCM here after) was focused for repairing material. Maximum size of aggregate was 2.5mm, type of cement was ordinary Portland cement, and quarts sand was used for fine aggregate. As for the mix proportions of this PCM, sand per cement ratio was 2.0 and polymer per cement ratio was 5%.



Picture 2: Appearance of canal

2.2 Summary of focused irrigation canal

We focused to one aged irrigation concrete canal in Kagawa prefecture in west Japan. This canal was used for irrigation for more than 40 years. The picture of this canal is shown in Picture 2, and cross section of this canal was described in Figure 1. Due to the aging on surface of concrete, surface covering technique was applied as the repairing method almost 8 years ago (constructed at 8^{th} to 20^{th} of May, 2006) using the PCM described above. Covering thickness was 10mm, and total repaired length was 2,250mm.

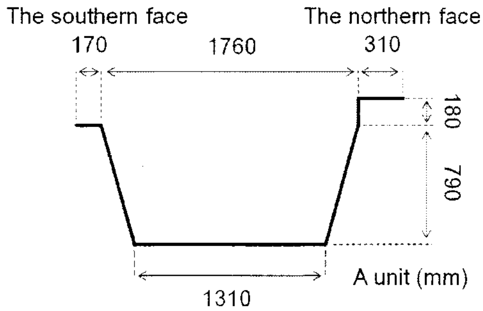


Figure 1: Cross section of canal

2.3 Evaluation on neutralization of PCM constructed for surface covering technique

Neutralization is one kind of deterioration. Alkalinity of mortar and concrete is lost due to the carbon dioxide gas penetrated into inner of concrete reacted chemically with calcium hydroxide existed as hydration of cement. In common, concrete is kept highly alkali condition, its pH is almost 12 to 13, and reinforcement bar is preserved from the corrosion. However, the corrosion of reinforcement starts when the pH falls down below pH 11. If the corrosion of reinforcement started, volume of reinforcement increased and cracks generated due to the expansion pressure.

Phenolphthalein ethanol solution is applied for the judgment of neutralization as this solution discolors into deep violet when the pH of concrete was higher than 8.2 to 10.0. It means if the color of concrete sprayed PP solution was not changed, we could judge the part had already carbonized. On the contrary, if the color changed, it means we can judge the part as sound condition [2].

Picture 3: Shaving hole by drill

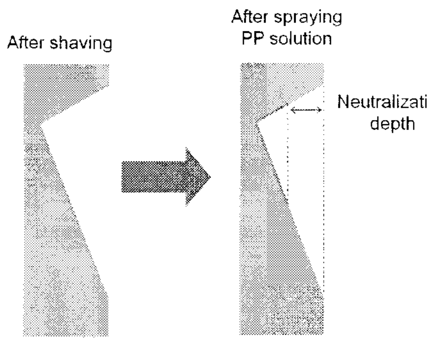


Figure 2: Abstract of measurement

In this experiment, measurement of neutralization was carried out with digging a diagonal hole to the sidewall of drainage concrete canal by drill shown in Picture 3, and PP solution was sprayed. Diagonal hole made the measurement of boundary between discolored and non-discolored zone easier than right angle hole. Abstract of this method is described in Figure 2. Position of measurement is shown in Figure 3. Totally 7 points were measured; 6 points at right bank of canal's sidewall and one point at the centre of canal's bottom.

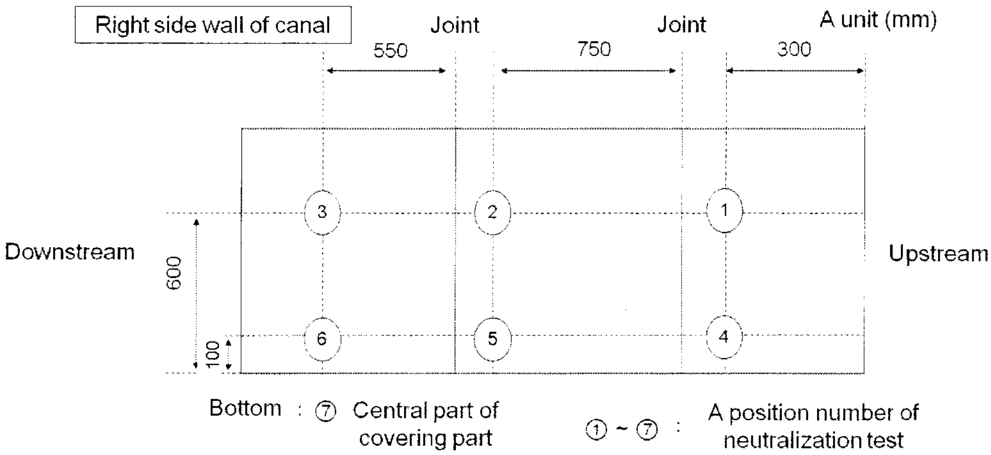


Figure 3: Measurement point of neutralization depth in concrete canal

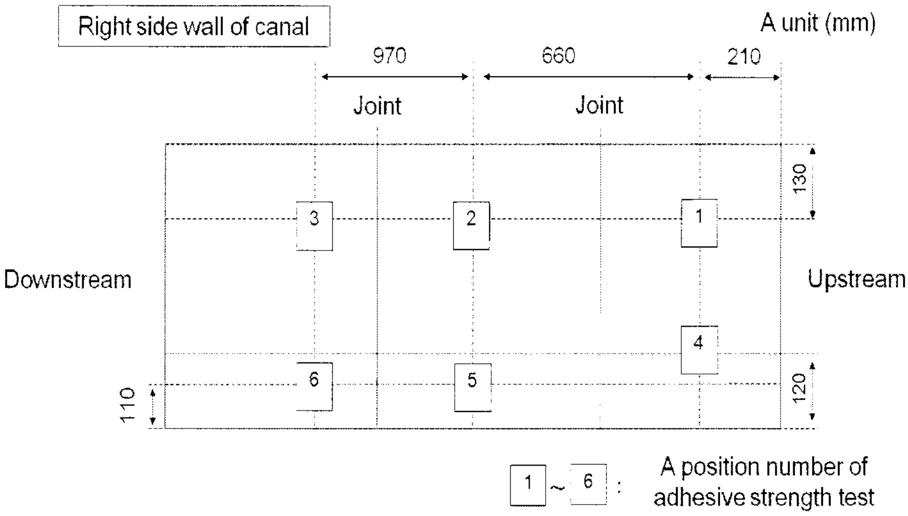


Figure 4: Measurement position of adhesive strength test in concrete canal

After getting the data of neutralization depth, prediction on progress of neutralization was calculated using following equation.

$$y = b\sqrt{t} \qquad (1)$$

Where the y is neutralization depth (mm), b is coefficient of neutralization velocity (mm・$t^{1/2}$), and t is the time (year). Coefficient of neutralization velocity is estimated in order to predict the time of arrival that the neutralization affect to the corrosion of reinforcement [3].

2.4 Evaluation on adhesive strength between covering material and base concrete

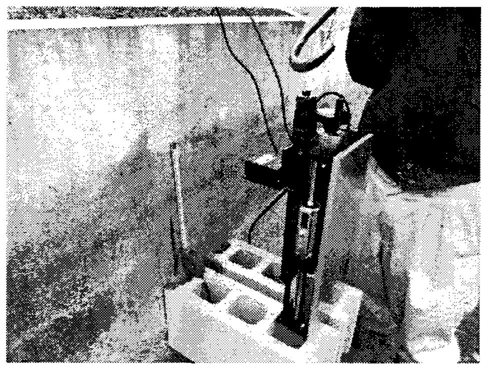
The material using for surface covering technique is required to be combined well with base concrete in order to restrict the peeling between them. As for the irrigation open channel, flow levels changed between irrigated and not irrigated terms, the moisture condition of concrete canal becomes different between them. This difference is considered to affect to the adhesive strength of surface covering material. Moreover, climate and temperature changes also affect to it. Under these severe conditions, enough durability and adhesive strength is required to the repairing material.

Direct tensile strength test method (single axis type) was applied for confirming the adhesive strength of PCM used in this study. The outline of this experiment was shown in Picture 4, and measurement point of adhesive strength in this canal was shown in Figure 4. Total points measured in this study were 6. All data were measured at right bank of canal's sidewall, 3 were upper part and 3 were lower part of sidewall. At first, the attachment was pasted using epoxy resin. After hardening, all the side of attachment was cut by the concrete cutter, and measured the adhesive strength.

Picture 4: Outline of adhesive strength test

2.5 Evaluation on abraded amount of covering material

Almost 8 years have passed since the repairing technique using PCM was applied against focused aged irrigation concrete canal. Therefore, resistance to abrasion under actual environment was evaluated measuring the abraded depth of PCM surface. Surface condition was measured using laser displacement test in this study. Automatic stage which could move a constant velocity was combined for managing the movement of this stage. Appearance of measurement was described in Picture 5. Algae and sludge stuck to the surface of concrete canal were removed completely. The air part, water part and draft part were mentioned to evaluate the influence of abrasion. In order to evaluate quantitatively, two indicators of surface roughness were calculated; one is the arithmetic roughness (*Ra*) and other one is the maximum height in the roughness (*Rz*). The idea of both indicators is shown in Figure 5. Furthermore, Manning's coefficient of roughness, representative indicator for hydraulic performance, was calculated with following equations respectively [4].



Picture 5: Outline of laser displacement test

$$n = 0.042(0.26Rz)^{1/6} \qquad (2)$$

$$n = 0.042(2Ra)^{1/6} \qquad (3)$$

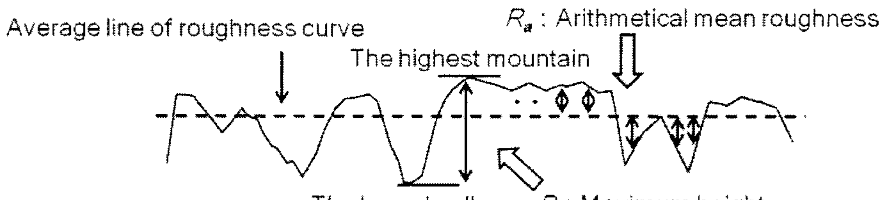


Figure 5: The idea of *Ra* and *Rz*

3 RESULTS AND DISCUSSIONS

3.1 Neutralization characteristic of PCM supplied at actual concrete canal

Neutralization depth and coefficient of neutralization velocity (called CNV here after) at each position were shown in Table 1. CNV was calculated with equation (1), and the time was 8 year. A point worth special mention was that the neutralization depth of sidewall concrete was different in the same member, between upper and lower layer, therefore, CNV was calculated with distinction of each layer.

From the test results, neutralization depths of lower layer (3 points) and bottom (1 point) are larger than those of upper layer (3 points). Comparing the average neutralization depth at each

Table 1: Neutralizaion depth and CNV at each position of concrete canal

Test position		Upper part of canal			Lower part of canal			Bottom
		No.1	No.2	No.3	No.4	No.5	No.6	No.7
Neutralization depth (mm)	First time	0.4	0.5	0.3	0.9	1.0	0.7	0.6
	Second time	0.4	-	0.4	0.7	0.9	0.7	0.7
	Third time	-	-	-	-	-	-	1.0
	Average of No.	0.4	0.5	0.4	0.8	1.0	0.7	0.8
	Average of position	0.43			0.83			0.8
Coefficient of Neutralization velocity (mm/ √year)		0.152			0.293			0.283

part in sidewall of canal, the depth of upper layer is two times larger than that of lower layer. On the contrary, the depth of lower layer and bottom showed similar values. As for the CNV of each position, neutralization velocity of upper layer of side wall is slower than that of other parts (lower layer and bottom).

Neutralization of concrete is progressing due to the penetration of carbon dioxide gas in atmosphere. Thus, in common, the neutralization velocity of concrete supplied in water considered to be smaller than that of concrete supplied in the atmosphere. The water in this canal flow all through the year, and the lower layer of sidewall and bottom of canal had been immersed while they were supplied. It meant the upper layer was possible to think it had been in the air, and its neutralization depth should be larger than other two parts that were considered to be in water. One of the factors of this phenomenon could be pointed out that the leaching of concrete excelled in neutralization. Leaching of concrete is one kind of deterioration of concrete, and classified of chemical attack. Fundamentally, the calcium hydroxide, one of the hydration products, dissolved in water and the organization of mortar became porous [5]. It meant that if the leaching were generating at the water part of concrete, the neutralization depth could be larger than the concrete supplied in the atmosphere.

However, on the whole, neutralization depth of PCM examined in this study was small enough in spite of supplied year (almost 8 years). Considering the 10mm thickness PCM at this canal, it was confirmed that at least 40 years would be necessary to reach the neutralization depth to the base concrete.

3.2 Adhesive strength characteristic of PCM in actual concrete canal

Adhesive test results at every part in this study were summarized in Table 2. Averaged adhesive strength at upper layer and lower layer in sidewall of concrete canal were calculated as 1.88 N/mm^2 and 2.40 N/mm^2, respectively. Destructive formations were all the same, destructed at the base concrete, at all positions (No.1 to No.6). For reference, maximum standard value of adhesive strength set at the manual [1] was 1.5N/mm^2. The test results showed all the points showed higher adhesive strength than every standard value of various conditions. Therefore, it was concluded that the adhesive strength of PCM used in this study did not have any problem at age 8 years.

Now we focused to the difference of adhesive strength between upper and lower layer in the same member (sidewall) of canal. The failure mode is fundamentally divided into 3 types shown in Figure 6. In this experiment, all the test results showed the failure mode of "base concrete destruction", this repairing material had higher adhesive strength than measured strength. It meant the difference between upper layer and lower layer was generated due to the difference of quality at upper and lower layer of base concrete. Such a sidewall concrete, the strength of lower position becomes larger than that of higher position due to the influence of

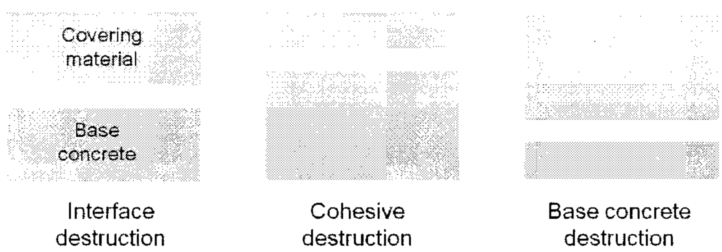


Figure 6: Typical failure mode of adhesive strength test

Table 2: Test results of adhesive strength at all position of concrete canal

Test position	Upper part of canal			Lower part of canal		
	No.1	No.2	No.3	No.4	No.5	No.6
Adhesive area (mm^2)	1600	1600	1600	1600	1600	1600
Load (kN)	3.34	3.19	2.50	4.02	3.86	3.64
Adhesive strength (N/mm^2)	2.09	1.99	1.56	2.51	2.41	2.28
Average of adhesive strength (N/mm^2)	1.88			2.40		
Destructive form	Base concrete	Base concrete	Base concrete	Base concrete	Base concrete	Base concrete

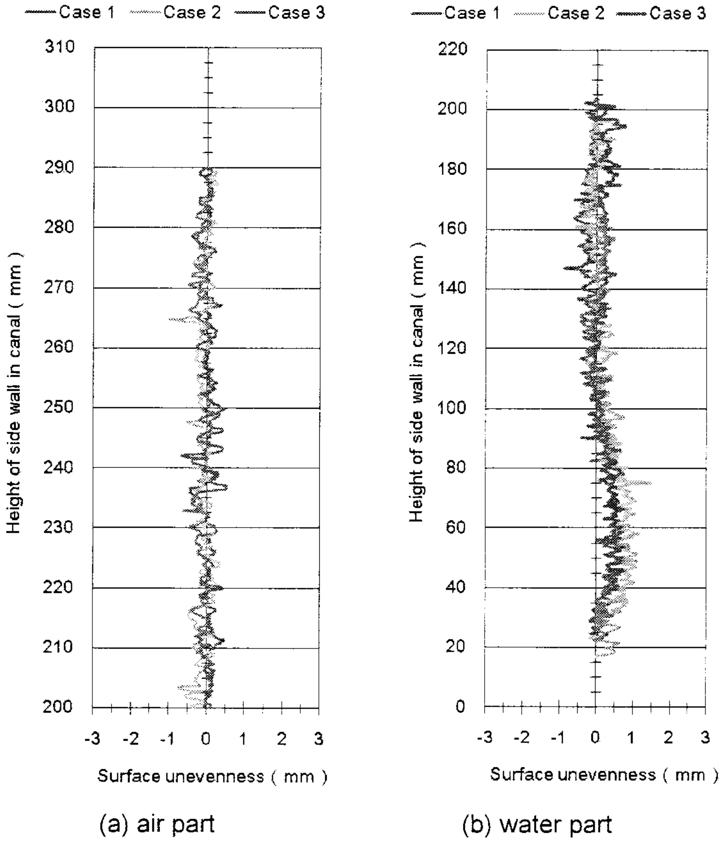


Figure 7: Surface condition at air part (a) and water part (b) of PCM

breeding and settlement of aggregate during the setting and compaction of fresh concrete. This influenced to the adhesive strength, the lower layer showed larger adhesive strength than higher layer. In addition, lower position of concrete canal was always soaked in water. It meant this part has been cured in water, thus, better environmental condition for keeping the strength of concrete.

On the contrary, upper layer of concrete canal was usually exposed to not only the atmosphere but also rainfall and/or water flow as the water level of canal would not be stable. Therefore, the surface of concrete at upper layer might generate the looseness because of the repetition of drying and wetting, and strength became getting smaller gradually.

Table 3: Calculation results on 3 indicators of surface roughness

Measurment position	Index of surface roughness (mm)					Converted roughness coefficient ($s/m^{1/3}$)	
	Average	Maximum	Minimum	R_z	R_a	$n(R_z)$	$n(R_a)$
Air part Case 1	0.05	0.51	-0.66	1.17	0.13	0.011	0.011
Air part Case 2	-0.06	0.52	-0.61	1.13	0.13	0.011	0.011
Air part Case 3	-0.09	0.40	-1.00	1.40	0.15	0.011	0.011
Air part Average	**-0.03**	**0.48**	**-0.75**	**1.23**	**0.14**	**0.011**	**0.011**
Water part Case 1	0.03	0.82	-0.88	1.70	0.27	0.012	0.012
Water part Case 2	0.30	1.47	-0.58	2.05	0.32	0.012	0.012
Water part Case 3	0.23	0.78	-0.44	1.22	0.17	0.011	0.011
Water part Average	**0.19**	**1.03**	**-0.63**	**1.66**	**0.25**	**0.012**	**0.012**

3.3 Abrasion characteristic of PCM in actual concrete canal

Abraded amount of PCM was evaluated after supplying for almost 8 years in actual canal as a repairing material. Surface conditions at air part and water part of PCM were shown in Figure 7. Three times measurement at each part were conducted in this experiment for assuring the accuracy. Draft part, the boundary of air and water part were positioned at 200mm height in each figure. Both parts showed not flat condition equally. A noteworthy event was appeared at the underneath of draft line (200mm), height of 20 to 100mm in Figure 7(b). It was possible to confirm the peculiar round shape at there. In addition, this round shape did not dent in but expand to out. Furthermore, when mentioning to the draft part, significant dent due to abrasion was not confirmed. Therefore, this round shape was considered to be original shape. In short, this shape was set from the beginning, when repaired this canal with this PCM, as PCM was constructed by hand. Further study would be necessary to clarify this hypothesis by monitoring from the beginning when surface covering were conducted.

Calculation results on indicators of surface roughness were shown in Table 3. It was possible to confirm the roughness of Ra and Rz had slight difference between air part and water part, respectively. On the whole, the roughness of air part is smaller than that of water part. However, these differences at each indicator is not so large, and we could conclude that effect of abrasion against this material was not significant even 8 years have passed after repairing. As for the Manning's coefficient of roughness, all the values were included in 0.011 to 0.012. In Japan, base value of this coefficient is set to 0.012 to 0.016 for concrete canal [6]. Therefore, we concluded that this repairing material is still keeping good hydraulic performance.

4 CONCLUSIONS

Focused to the evaluation on long-term performance of PCM, one kind of typical inorganic repairing material for irrigation concrete canal, the results obtained in this study were summarized as follows:

1) Neutralization depth and CNV of PCM was very small under actual environmental condition.
2) Advance of neutralization was different in same member. Therefore, it is necessary to be careful when evaluating the neutralization.
3) Adhesive strength of PCM after almost 8 years was larger enough comparing with standard value for inorganic repairing material.
4) Even at the water part of canal, no abrasion of PCM was confirmed after 8 years supplying at actual concrete canal.
5) All the indicators concerns to surface roughness of PCM showed better hydraulic performance rather than concrete canal.

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