Proceedings of the 4th Asian Wave and Tidal Energy Conference (AWTEC 2018), Taipei, Taiwan, September, 2018.

Observation of biofouling by using test plates in Hirado Strait of Nagasaki, Japan

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***Abstract*—Relating the cost of the tidal power generation, the bio-fouling effects on the tidal turbine may be important since it is relevant to the maintenance cost of the power device for a long time. Field measurement results of the bio-fouling effects on test plates at the Hirado-Seto Strait in Nagasaki Prefecture are reported. Test plates include 5 plates without paint and a plate with silicon paint and 4 plates with anti-fouling offshore structure and ship bottom paints. The experimental frame with the test plates are hung from the breakwater into the sea and are raised from the sea every month regularly to observe the bio-fouling by taking pictures and measuring the weight of the plates. It is clarified that the dominant species around the adjacent sea are the triangle- and red-barnacles which do not newly attach if seawater temperature becomes below 20 degree in centigrade, but it continues to grow even in winter if it once attached. Observation is still running since September 2013 and the results for more than 3 years are presented.**

***Keywords* —Biofouling, Test plate, Tidal Current, Paint, Barnacle**

I. INTRODUCTION

Most significant point of the tidal power generation is its predictability, which is quite different from other renewable energies and therefore tidal power is regarded as the reliable energy source. A commercial purpose project called as “MeyGen” in Scotland is just started from January 2017 after two years preparations, and the similar projects in France and Canada are currently underway. In Japan, the promotion of realization of tidal current power generation by the Ministry of Environment has been started in Goto, Nagasaki Prefecture from July 2016. Some uncertainties such as the efficiency, durability and cost of tidal power generator among a long term operation are expected to be clear through the demonstration experiment in the sea.

The biofouling effect on the tidal power generator is one of important problems to solve before the deployment, because it is relevant to the maintenance period and the cost of the power. Especially, most of major power generators have been developed at EMEC in Scotland, where the maximum water temperature is below 15 degree while it is more than 25 degree in Goto, Nagasaki, therefore there may be big difference in the marine ecosystem between both seas.

Authors conducted the demonstration experiments of the tidal current power generator at the pier of Ikitsuki Bridge, Hirado city, Nagasaki for 8 months from August 2012 to April 2013.[1] Then, we understood the importance of the biofouling effects by barnacles on the tidal turbine, but there was no systematic data on the biofouling in the sea with the

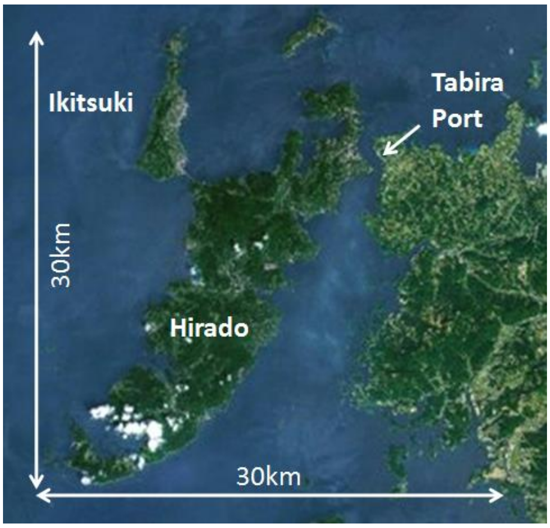

Fig.1 The test site map in Hirado-Strait

Fig.2 Test site at the breakwater in Tabira Port

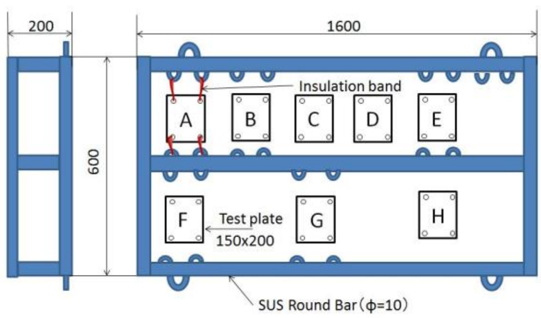

Fig.3 Biofouling test device, size and structure

fast tidal current. We conducted the biofouling observation using test plates with/without paint since September 2013 and the observation is continuing still now.[2] In this report, we present the observation results for more than three years.

II. EXPERIMENTAL SITE AND THE DEVICE

Fig. 1 shows the map of Hirado Strait and the location of the Tabira Port. The experimental site is at a point of the breakwater of Tabira Port in Fig. 2, where the tidal current is strong since it is near from the narrowest part of Hirado Strait. This site is about 80 km in the Northeast from the Naru Strait of Goto Islands where the tidal current power project by the Ministry of Environment is currently underway and the ocean environment of both sites may be quite similar.

Fig. 3 shows outline of the experimental device used in this study, where five plates in the upper row were painted and the five plates in the lower row were not painted. Test plates are made from PVC (polyvinyl chloride) plate of (H x B x t = 200 x 150 x 5 mm), and they were hooked by the plastic band to the flame of the experimental device.

Five painted plates were painted by the Chugoku Marine Paints Ltd(CMP), including the silicone paint (A), Powerclean 2000 (B, C) and Seagrandprix 66HDS (D, E) in Table 1. Durable years are 4 years and 2 years depending on the number of painting times, 2 and 3. Five plates without paint is distinguished by the immersion period of 1 month, 3 months, 6 months, 1 years and indefinite.

Fig. 4 shows the set-up of the experimental device hung from the breakwater in water 2m above the sea bottom. Since the breakwater is a kind of wave absorbing type, the tidal current speed may not be reduced much by the breakwater.

The first immersion of the device was made on 13th September 2013. Since then, regular observation has been conducted once a month around 11th day of the month. Fig.5 shows a picture taken just after the recovery on 11 December 2013, 3 months after the starts. In the regular observation, taking pictures of both sides of the plate, measuring the weight of each plate, and the data download from the water temperature meter are conducted within 2 hours. The reason why this observation is stably possible in the channel with strong tidal current is that the venue is on the breakwater so that we can access on foot without effect of weather condition. Furthermore, there is a locked fence in the middle of the breakwater so that other people are restricted to access there. We thank greatly the Nagasaki Prefectural Civil Engineering Office for their permission of us to use the breakwater for this observation.

III. RESULTS

3.1 Tidal current and water temperature

First, let us describe the physical environment of the experimental site. Fig. 6 shows the hodograph of the horizontal velocities (u,v) at 5 m above sea bottom measured

Table 1 Kind of paint of test plates

Plate	Kind of paint	Durable years
A	Silicon synthetic resin coating (CMP, Bioclean ECO)	4
B	Self-abrasive antifouling paint (CMP, Powerclean 2000)	2
C	Self-abrasive antifouling paint (CMP, Powerclean 2000)	4
D	Self-abrasive ship-bottom paint-2 (CMP, Seagrandprix 660HS)	2
E	Self-abrasive ship-bottom paint-2 (CMP, Seagrandprix 660HS)	4

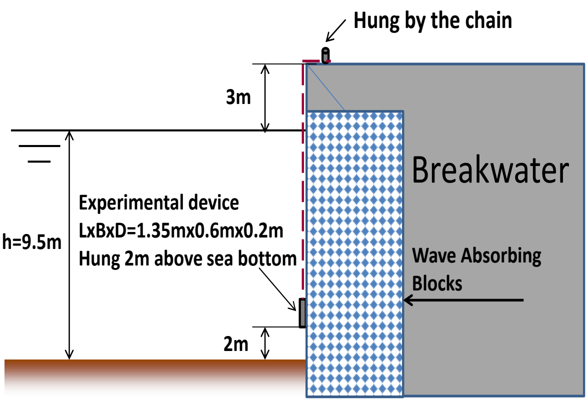

Fig. 4 Sketch of the set-up of the experimental device at the site

Fig.5 Picture of the biofouling test plates after 3 months on 11 December 2013

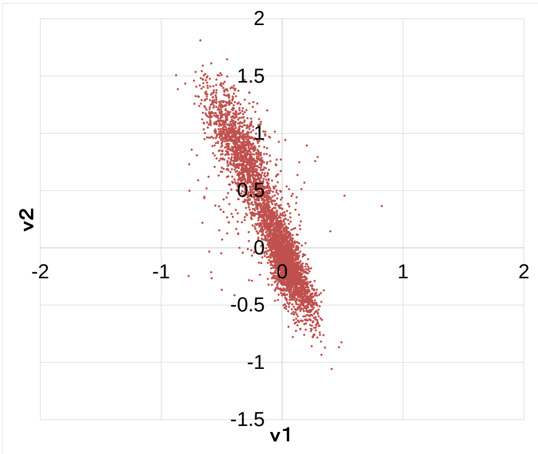

Fig.6 Hodo-graph of the tidal current (u, v) at 5 m above sea bottom at the site

by the ADCP deployed 5m offshore from the observation site from 11th November to 11th December 2013, where each dot was obtained every 10 minutes. Results show that the maximum speed of the flood tide reached about 1.7 m/s in Northwest direction while it was about 1 m/s during ebb tide. The flow direction was same as the breakwater. Reason why the tidal speed during flood tide is stronger than ebb tide is easily understood by the local topography of the Hirado Strait shown in Fig.1 and Fig.2. From these results, the present observation site is judged as quite adequate for the observation of the biofouling in strong tidal current.

Next, Fig. 7 shows the results of water temperature at the site for two years from 11th October 2013 to 30th September 2015. From these results, the minimum water temperature went down around 13 degrees during February or March and the maximum reaches to higher than 26 degrees in August. The results of the water temperature are quite different from those of the sea of the European Marine Energy Centre (EMEC) of Scotland, UK. Water temperature at EMEC is said to be less than 15 degrees throughout the year. This means that the ocean environment and the eco-system of Nagasaki waters may be quite different from Scotland waters. Therefore, it is important to understand that a tidal current turbine developed in EMEC may not directly applied to other seas in some parts related to the local ocean environments.

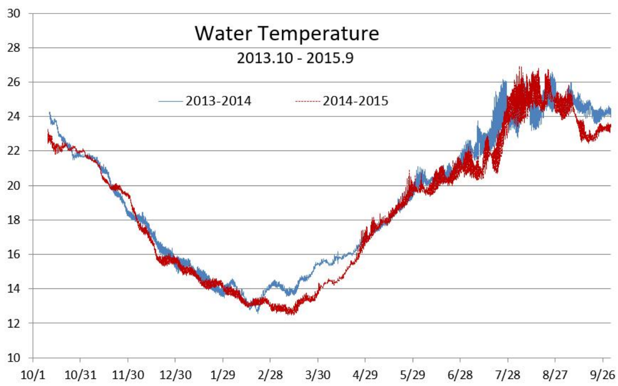

Fig.7 Variation of water temperature during two years

3.2 Kinds of sessile organisms on the test plates

Fig. 8 shows the picture of the experimental device just after raised from water on 11th September 2014 after one year deployment. From this picture, we understand the big difference between painted or no painted plates. There was no barnacle attached on the painted plates although the biofilm or algae was seen on the surface. On the other hand, we could see a large amount of sessile organisms on the plates without paint in the lower raw. We found 13 species of plants including green algae, brown algae and red algae. For marine creature, we found 29 species including the arthropod, soft-bodied creature, bivalves and echinoderms but more than 99% of the weight of them was occupied by triangle-barnacles (*balanus trigonus*) and red-barnacles (*Megabalanus rosa*).


Fig.8 A picture of the bio-fouling test device after one year on 11 September 2014

Fig.9 shows the picture of the face and back surfaces of one-month plate on 11 September 2014. We can observe the face side was covered by the green algae and some baby barnacles were attached, while the back side was no color but baby barnacles more than face side were found. This fact that the number of barnacles on the back side of one month plate was more than the face side was applied normally every month.


Fig.9 Face and back of one-month plate on 11 September 2014

Fig. 10 shows the picture of 3 months plate. Face side was fully covered by brown colored barnacles. Back side was also covered by barnacles but total number was less than the face side. Difference in colors between face and back sides in Figs 9 and 10 may be attributed to the algae on the surface, which relates the effects of sunlight.


Fig.10 Face and back of three-month plate on 11 September 2014

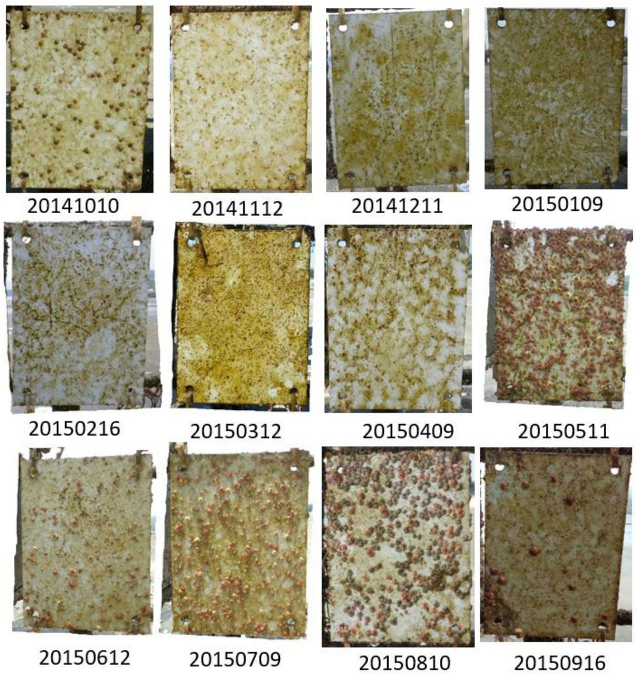

Fig.11 One month plates from October 2014 to September 2015

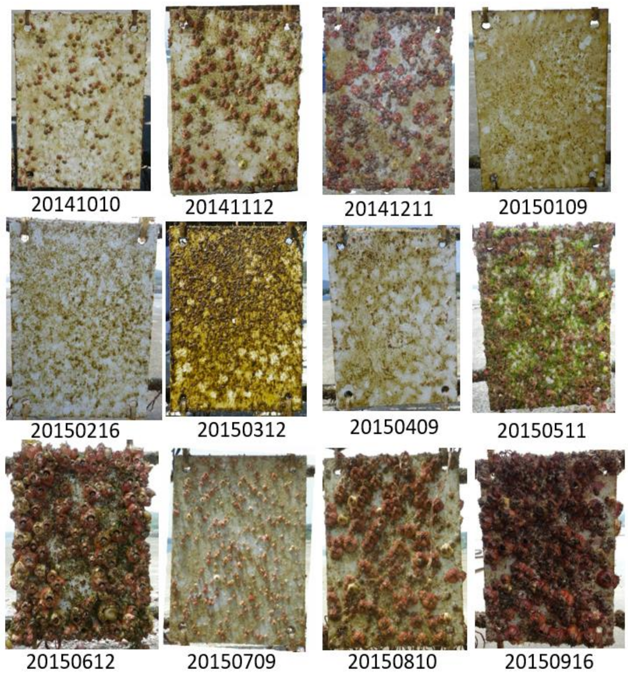

Fig.12 Three months plates from October 2014 to September 2015

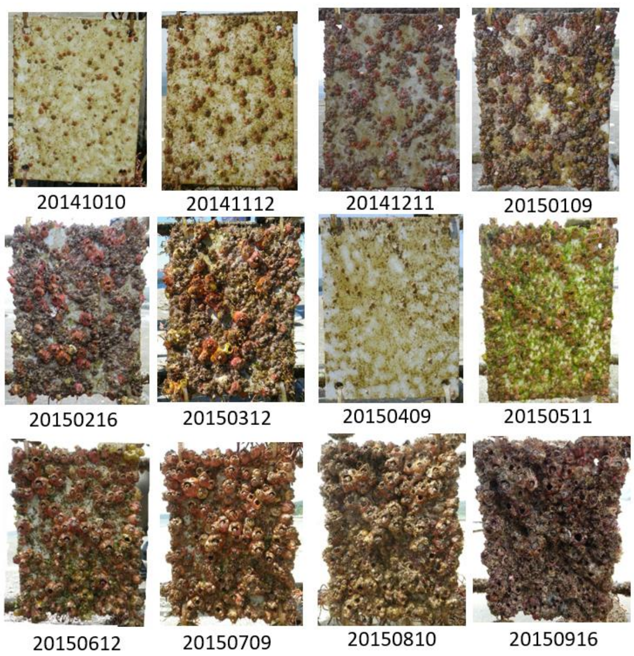

Fig.13 Six months plates from October 2014 to September 2015

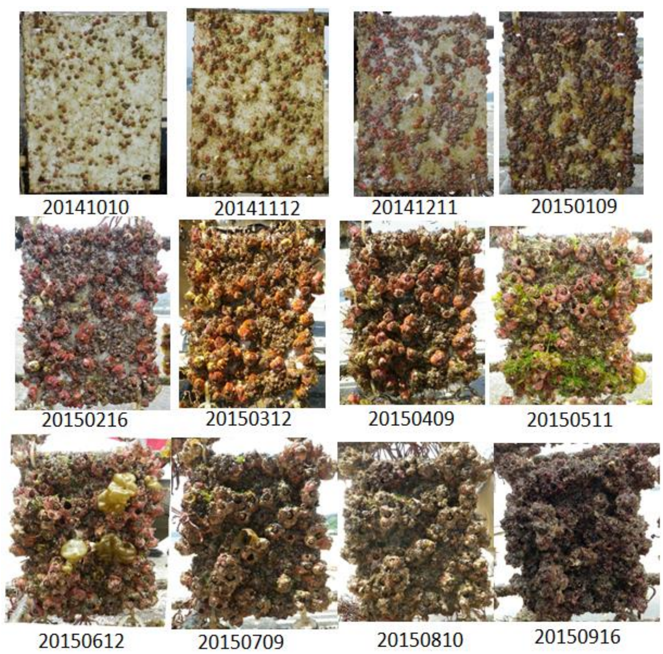

Fig.14 Twelve months plates from October 2014 to September 2015

3.3 Transition of surface of the test plates without paint

Fig. 11 shows pictures of the face side of one month plate from October 2014 to September 2015. One month plate is recovered and changed to a new plate every month and the number under the picture denotes the date of recovery after one month immersion. We understand that almost no new barnacle attached during winter from December to March, which may be explained that barnacles do not spawn if the water temperature is below 20 degrees. Except winter, many baby barnacles of various size attached on the surface. The number of barnacle was small but the size was big and all of them was a red barnacle for the plate of September 2015. Most weight increase was found in May and the next was August 2015.

Fig.12 shows pictures of the three month plates, which were changed in March, June, September and December. We can see only the brown algae on the plates in winter from January to March. The heaviest plate was observed in June. A

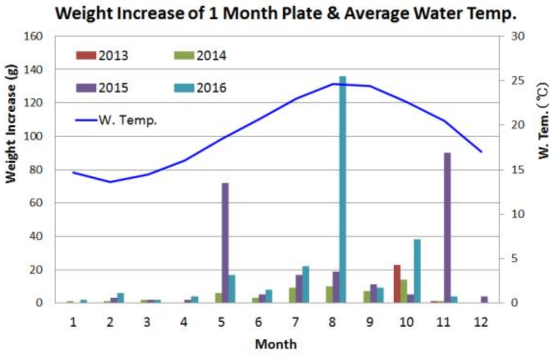

Fig.15 Variation of weight increase of one month plate from October 2013 to December 2016

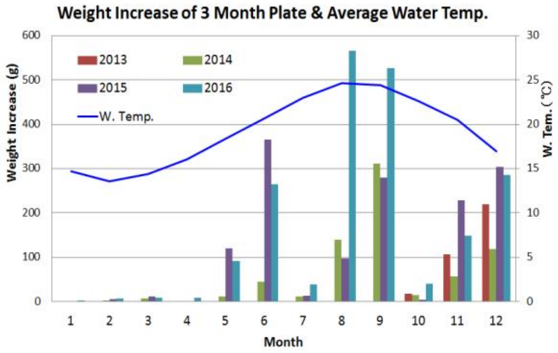

Fig.16 Variation of weight increase of 3 month plate from October 2013 to December 2016

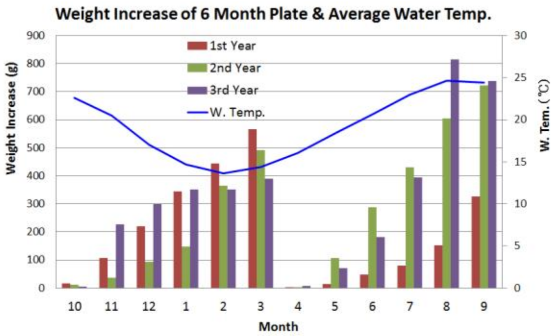

Fig.17 Variation of weight increase of 6 month plate from October 2013 to September 2016

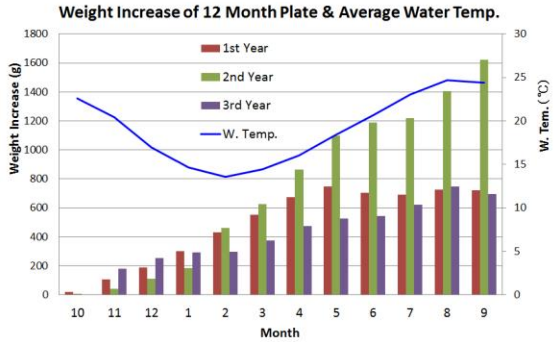

Fig.18 Variation of weight increase of 12 month plate from October 2013 to September 2016

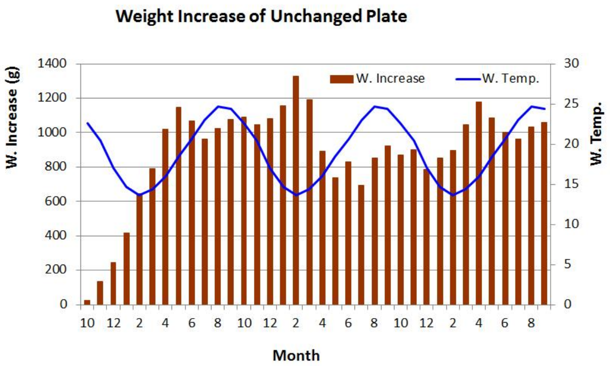

Fig.19 Variation of weight increase of unchanged plate from October 2013 to September 2016

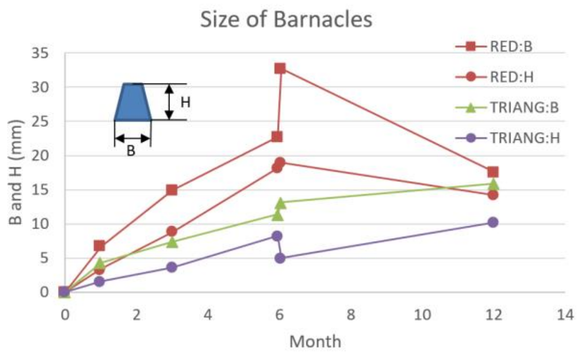

Fig.20 Maximum sizes (B, H) of red barnacle and triangle barnacle collected from 1 month, 3 month, 6 month and 12 month plates

plate from October to December showed that the barnacles kept growing even in December.

Fig.13 and Fig.14 show the pictures of 6 month plate and 12 month plate. They were quite same condition until March 2015, so that the growth of both plates was similar. The weight of 12 month plate showed the saturation after 8 month because there was no more space for barnacles to attach and grow on the plate.

Fig.15 shows the monthly weight increase (net weight of attaching organisms) of one month plate for 3 years and 3 months, together with the monthly averaged water temperature. Normally, weight increase becomes high from May to October, when water temperature goes up 20 degrees, but the weight increase sometimes takes abnormally high like May and November 2015 and August 2016, although the reason is not clear.

Fig.16 shows the weight increase of 3 month plate. The weight increase of the plate of January to March in winter is almost zero, while it is high in December which means barnacles already attached before winter kept growing as same as other seasons.

Fig.17 shows the weight increase of 6 month plate. The weight increase normally grows high proportional to the time but it is clear that there is variation in growth rate depending on the year. The similar conclusion is applied to 12 months plate in Fig.18. The weight increase of 1st year was saturated after May 2014 and the difference of the weight increase in years is not small. The final weight increases were 721g (1st year), 1,622g (2nd year) and 698g (3rd year), it of the second year was larger more than double than the other years.

Fig.19 shows the transition of the weight increase of unchanged plate for three years. The weight became the maximum eight months later from the deployment and repeated the increase and decrease afterwards. The reason of the decrease may be the external loads by strong tidal current and waves. It is interesting to see the maximum weight appeared from February to April but the variation of weight seems not to correlate with water temperature.

Fig.20 shows the maximum diameters and heights of red-barnacle and triangle barnacle taken from 1 month, 3 month, 6 month and 12 month plates. Two values from 6 months plate were taken from two samples. Size of triangle barnacle is generally smaller than red barnacle. The sizes of red barnacle from 12 months plate were smaller than those from 6 months plate, which might be explained by the same reason why the maximum weight appeared at 8 months later in Fig.19, that is the large barnacles dropped from the plate after 8 months..

3.4 Transition of surface of the test plates with paint

Comparing the plates without paint, there were no big changes in the painted plates for 1 year and 6 months. However, first biofouling effect appeared on plate "A". Fig.21 shows the pictures of plate "A" from April 2015 to March 2016. We understand how red barnacles grew on the plate every month. Some barnacles sometimes disappeared on the plate but one red barnacle in the center of the plate could grow stably and continuously during this period.

Fig.22 shows the transition of the weight of the plate "A". The weight of the plate drastically increased and the maximum weight reached 800 gram almost same level as plates without paint in Fig.18 or Fig.19. After taking the maximum weight in November 2016, the plate lost the weight rapidly, perhaps due to the severe weather condition in winter.

On the contrary to the face side of the plate, there was no barnacle attached on the back side. This difference is not clear but it might be explained by that the paint on the face side of the plate was washed out by the strong tidal current.

Figs. 23 to 26 show the pictures of the painted plates "B", "C", "D" and "E" from April 2016 to March 2017. All the plate was painted by the self-abrasive antifouling paint, so that they became lighter with time as shown in Fig.27. The weight of the plate "B" was gradually reducing for 3 years and 4 months but it suddenly began to increase because some barnacles attached on the flank of the plate "B" after November 2016 as shown in Fig.23.

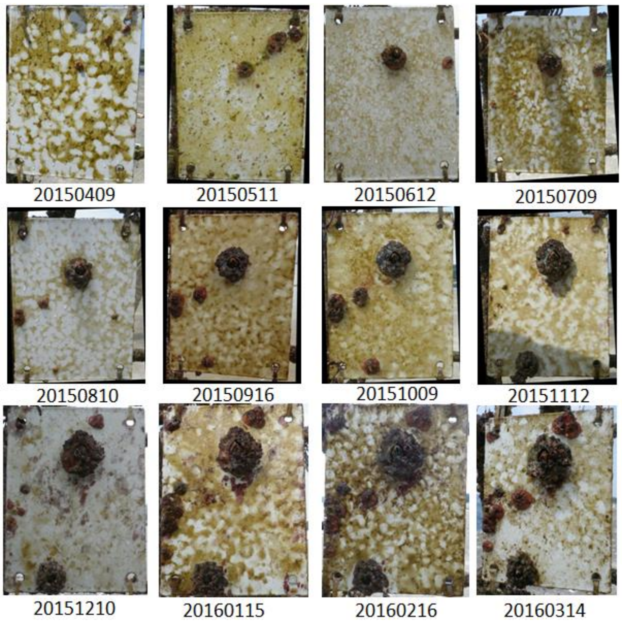

Fig.21 Painted plate "A" from April 2015 to March 2016

Comparing the pictures of Figs.23 and 24, it is observed that both plates became similar situation in color on the surface from brown to black. Some barnacles once attached on the plate were observed to disappear one or two months later.

Although the plates "D" and "E" were not serious condition, the similar comments as "B" and "C" can be applied to Figs. 25 and 26. If the paint is scoured from the surface and does not work as antifouling paint, the weight of the plate "D" and "E" will also increase as same process as "B" in Fig.27. We want to know how long the plates "C", "D" and "E" are OK and are continuing this observation until finding it.

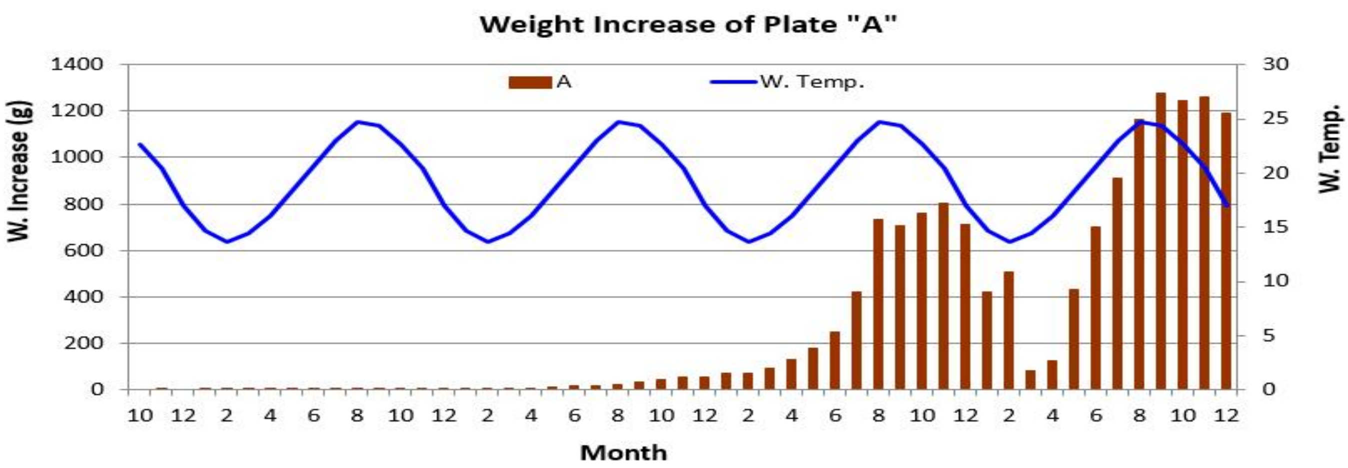

Fig.22 Weight increase of painted plate "A" and the monthly averaged water temperature from October 2013 to December 2017

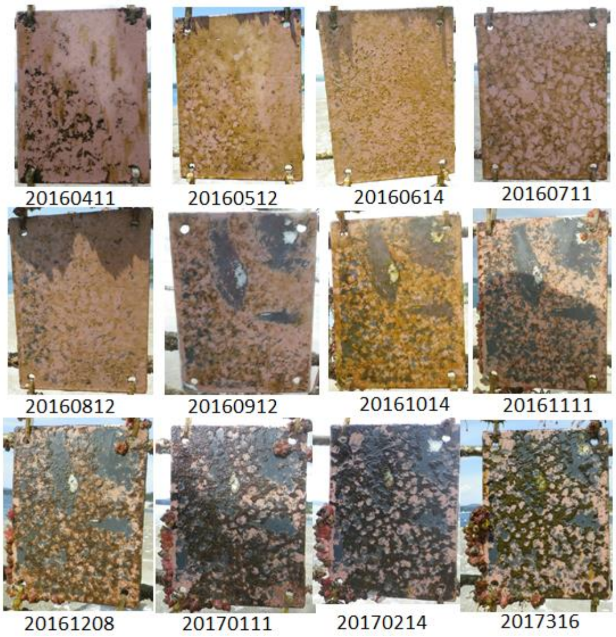

Fig.23 Painted plate "B" from April 2016 to March 2017

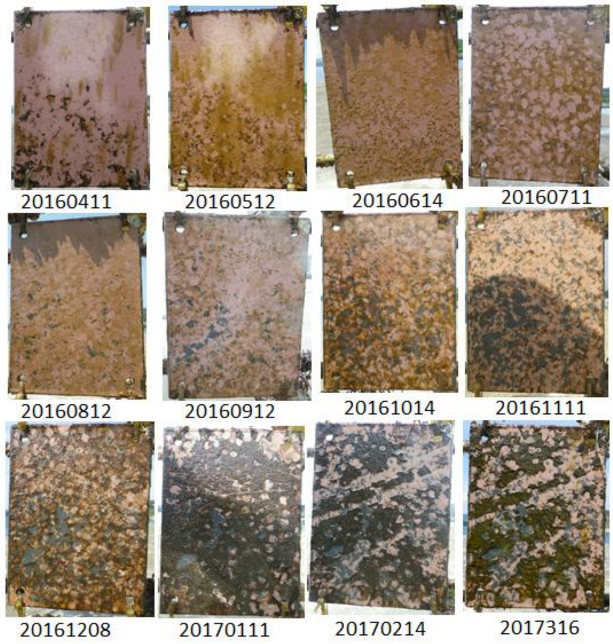

Fig.24 Painted plate "C" from April 2016 to March 2017

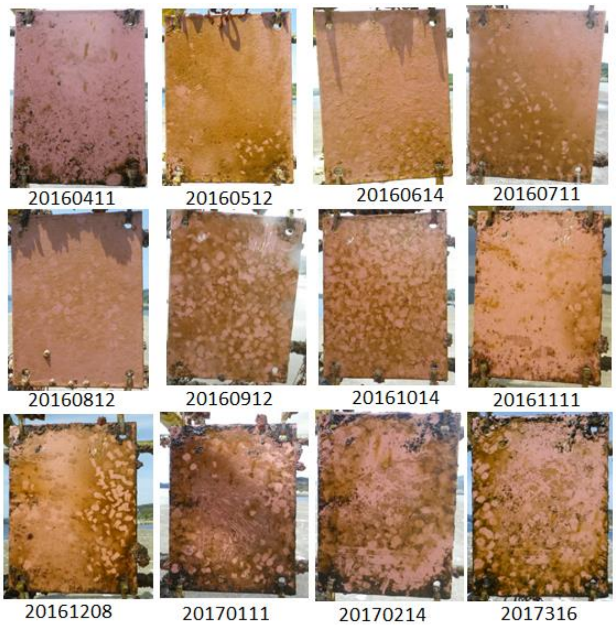

Fig.25 Painted plate "D" from April 2016 to March 2017

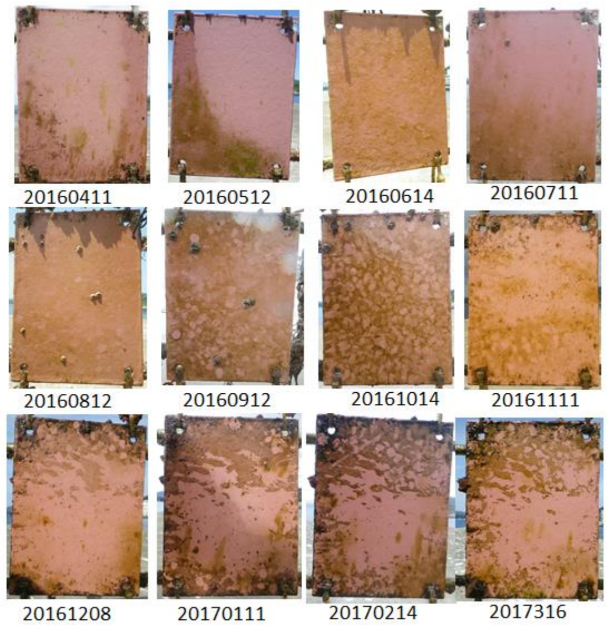

Fig.26 Painted plate "E" from April 2016 to March 2017

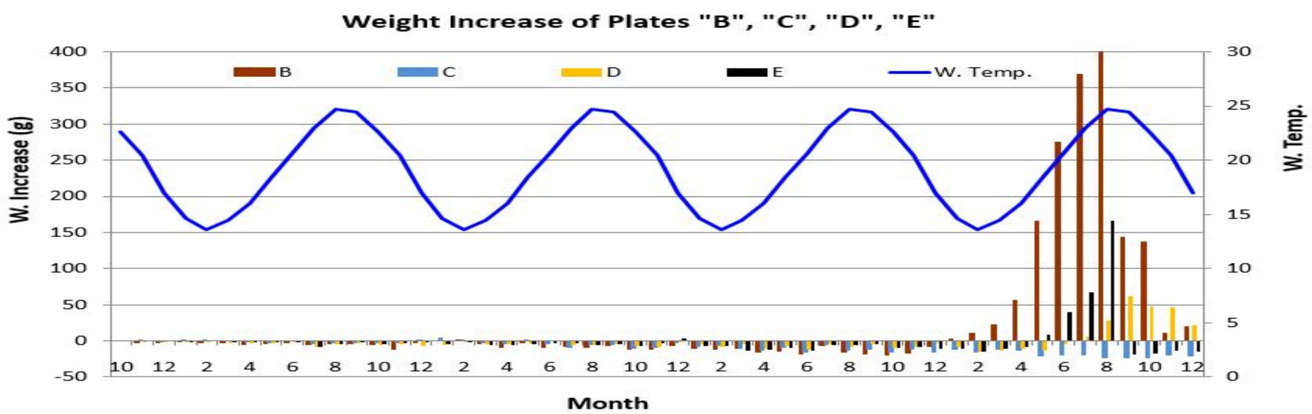

Fig.27 Weight increase of painted plate "B", "C", "D", "E" and the monthly averaged water temperature from October 2013 to December 2017

IV CONCLUSIONS

Relating to the maintenance cost and period of the tidal current power generation in Goto Islands, Nagasaki Prefecture, we conducted the biofouling observation using the test plates in the Hirado Strait, where the maximum tidal current is more than 1.7 m/s. Ten test plates include 5 painted plates by 3 kinds of paint and 5 plates without paint were used in the observation, in which the weight of each plate is measured and a picture of the plate is taken every month since October 2013. After the 3 years and 6 months observation, we obtained the following conclusions:

(1) Many triangle- and red-barnacles, which are dominant species in this sea area were attached on the plates without paint.

(2) There were seasonal and yearly variations in the weight increase of the test plates depending on the growth rate of the barnacles. New barnacles seldom attached during winters because they do not spawn if the water temperature is below 20 degrees, but the barnacles attached before winter could grow even during winter.

(3) Number of barnacles on the face side of the plate without paint was less than back side one month later the deployment but the growth rate of the barnacles was greater than back side so that large barnacles were found more on the face side.

(4) Test plate “A” with silicon synthetic resin coating was thought to be most convincing at first, but the effect of the paint had lost 18 months later and many barnacles attached on the surface of face side. On the contrary, no barnacle attached on the back side, so that the paint on the face side might be scoured by the strong tidal current and waves.

(5) The weights of four plates with self-abrasive biofouling paints were reduced with time but the effect lasted more than 3 years. Regarding the plate “B”, weight suddenly increased afterwards by barnacles attached on the plate after 3 years and 4 months.

We want to continue the observation to find out how long the anti-biofouling effects of the plates “C”, “D” and “E” will last.

ACKNOWLEDGEMENT

The authors are grateful to the Civil Engineering Office of Nagasaki Prefecture for the permission of the usage of the breakwater at Tabira Port. They express their sincere thanks to Mrs. Masayuki. Ida and Shohei Kawatoko who were the graduate students of Kyushu University in those days, for their cooperation for conducting the observations.

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