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Enhancing settlement and growth of corals using feeble electrochemical method

Kazuyoshi KIHARA[1,*], Hiroki TANIGUCHI[2], Yukio KOIBUCHI[3], Satoru YAMAMOTO[4], Yasufumi KONDO[5], and Yasushi HOSOKAWA[1]

[1] Mitsubishi Heavy Industries Bridge & Steel Structures Engineering Co., Ltd., 3-3-1 Minatomirai, Nishi, Yokohama 220-8401, Japan

[2] Akajima Marine Science Laboratory, 179 Aka, Zamamison, Okinawa 901-3311, Japan

[3] The University of Tokyo, Graduate School of Frontier Sciences, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-0882, Japan

[4] The Nippon Corrosion Engineering Co., Ltd., 1-21-12 Minami-Kamata, Ota, Tokyo 144-8555, Japan

[5] C.P. Farm Co., Ltd., 2-724 Ibaruma, Ishigaki, Okinawa 907-0332, Japan

* Corresponding author: K. Kihara
E-mail: kazuyoshi_kihara@mbe.mhi.co.jp

Abstract Considerable interest has been generated by the potential application of electric-fields to promote settlement of coral larvae and enhance growth rates of coral juveniles. Also, it has been reported that when an electric current is run through an attached iron base, coating by the resultant accretion of minerals through electrochemical processes, promotes the growth and survival of transplanted coral fragments. However, further investigations are required due to currently very limited scientific evidence.

In the present study, the optimal range of electric current density for coral growth was investigated through field observations in Okinawa. It was found that naturally settled reef-building corals on the surface of a floating pontoon, on which an electrical treatment was applied to prevent corrosion, grew faster in the areas where the actual electric current density was greater than 10 mA/m^2. An in situ experiment was, then, carried out on coral fragments that were attached to four iron-framed structures installed on the seabed with different feeble current densities. As a result, the coral fragments with the current density of 20~100 mA/m^2 showed relatively, but not always, faster growth than others. It was suggested that adverse effects might occur under strong electric currents. On the other hand, larvae exhibited far greater settlement affinity for the mineral accreted substrates without electric current than for the unglazed ceramic plates.

Keywords coral reef restoration, electric field, weak current density, growth promotion

Introduction

Coral reef restoration is a very important issue for reefs around Okinawa, Japan where degradation has been obvious in the recent decades. The settlement phase of coral larvae and the growth and survival of juvenile corals after settlement are major factors that affect the recovery of coral reefs. The application of an electric-field for promotion of larval settlement and growth of coral juveniles has attracted considerable attention. It has been reported that a) electrochemical accretion creates a substrate favorable for larval settlement, and b) a direct electric current enhances growth of coral fragments attached to the cathode side of an iron-frame (Onishi and Kudo 1989; Hilbertz and Goreau 1996).

Previously, various values of the electric current, mostly greater than 1 A/m^2 and typically around 3 A per m^2 have been proposed for the accretion process (Sabater and Yap 2002; van Treeck and Schumacher 1997). During the accretion process, applied electric current decreases gradually due to the increase of electric resistance by mineral accretion on the cathode (Hilbertz 1992; Schumacher and Schillak 1994). However, actual electric current densities working on the cathode during accretion have not been reported due to the lack of tools for in situ measurement.

For enhancement of growth and survivorship of coral fragments, several in situ trials of electric current running through an iron base, which was coated by accretion minerals through electrochemical processes, have been undertaken (van Treeck and Schumacher 1997; Sabater and Yap 2002). Electric currents of several to 10A have been applied, there. Goreau et al. (2004) also conducted their in situ electric current experiment and showed increment of zooxanthella in the corals during the experiment. However, actual electric current density around the coral fragments has not been measured. The experimental condition and growth performance of corals have not been shown clearly with scientific data set in another experiment (Goreau and Hilbertz 1996). Thus, there exists a need for further investigations on the scientific evidence of the effect of the electrochemical method on growth rates with appropriate operating conditions (Omori 2006; Kaufman 2006; Symons et al. 2006).

In the present study, we primarily focused on the effects of electric current on the growth of corals. The optimal range of the electric current density was estimated from in situ measurement. First, we present observation of corals growing on a hybrid type of pontoon on which an electrical treatment with a weak current was applied to prevent corrosion. This observation inspired us to further investigations. Then, we report results of a two-year in situ experiment on the growth of juvenile corals attached on an iron-frame using different electric currents. Finally, we show the effectiveness of larval settlement on mineral accreted substrates using the electrochemical method.

Material and methods

Inspiring field survey of corals on a pontoon

A hybrid-type of pontoon at Taketomi-higashi Port in Okinawa was installed in 2004. This facility is composed of a floating box made of steel and concrete, with steel fin-plates attached to the bottom of the box (Fig. 1). To protect the iron steel from corrosion under the sea, anticorrosion treatment was electrically applied. The most important factor for the anticorrosion system is to maintain the electric potential (voltage) below the oxidation reaction. Accordingly, it is sufficient to apply only a small electric current to the steel surface.

After six month from the installation, many young reef-building corals were observed growing naturally on the side surface of the pontoon though there were almost no corals on the neighboring seawalls without electric current. Even during severe coral bleaching events in the summer of 2007 and 2008, the corals on the pontoon continued to grow. We invented an in situ electric current

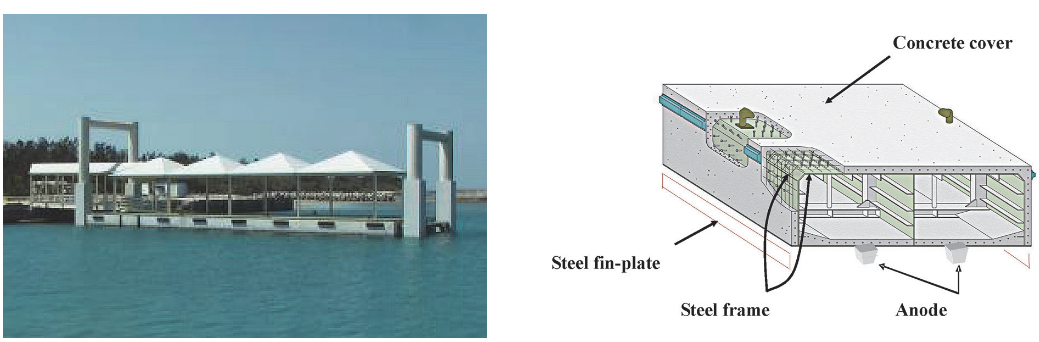


Fig. 1 Photograph and schematic representation of the hybrid-type pontoon installed at Taketomi-higashi Port

meter, and started monitoring a) the number of coral colonies on the surface, and b) the electric current density (mA/m^2) at the growth point since 2008. The current density was weak and varied from 1.0 to 42.5 mA/m^2.

Fig. 2 shows the relation between actual electric current density and number of coral colonies per unit area in 2009. The number of colonies was greater in the area where the electric current was highest within the observed range. Among the various species found growing in the surface area, *Pocillopora* spp. was the most abundant at those places where the current density was 10.0–42.5 mA/m^2, whereas a considerable number of Acropora spp. was found at places where the current density was 2.7–9.9 mA/m^2. *Pocillopora* spp. appeared to show a relatively high response to the electric current. These observations suggest that the response of corals to the electric current may vary with species, but apparently a weak electric-field affects settlement and growth of corals. A similar trend was observed at another pontoon on the neighboring Kuroshima Island. These observations were the bases for our experiments.

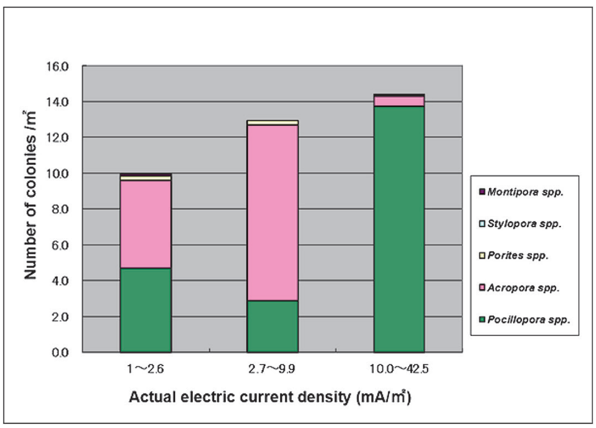


Fig. 2 Electric current density and number of coral colonies on the pontoon surface

Field experiment on growth promotion

The object of the experiment was to monitor the effect of a weak electric current on the growth of corals. A hemi-cylindrical iron-frame structure was prepared; it enclosed a magnesium (Mg) anode as shown in Fig. 3. Four structures were set adjacent to each other on the sea bed (depth: −6 m) off Ishigaki Island, Okinawa in April 2007.

Four different densities of the electric current were initially designed to apply for these structures; i.e., null (0), 100, 300, and 500 mA/m^2. These novel structures required neither any external power sources nor the cables from these sources on land, because combination of a magnesium anode and an iron-frame cathode in the seawater effectively constitutes a battery that provides electricity. Current density at work was initially expected to be almost the same over the entire surface of the iron-frame cathode. However, in practice, it varied spatially because of the local variations in the thickness of the deposited mineral layer and the distance from the anode. Spatial distribution of the current density eventually stabilized and the overall current density decreased with time because of the increased electrical resistance due to the deposited accretion. Actual current density (measured density) for the 100 mA/m^2 structure ranged 20–40 mA/m^2, that for 300 mA/m^2 was 40–140 mA/m^2 and that for 500 mA/m^2 was 100–200 mA/m^2 in June 2008. Actual current density observed here (0–200 mA/m^2) covered the

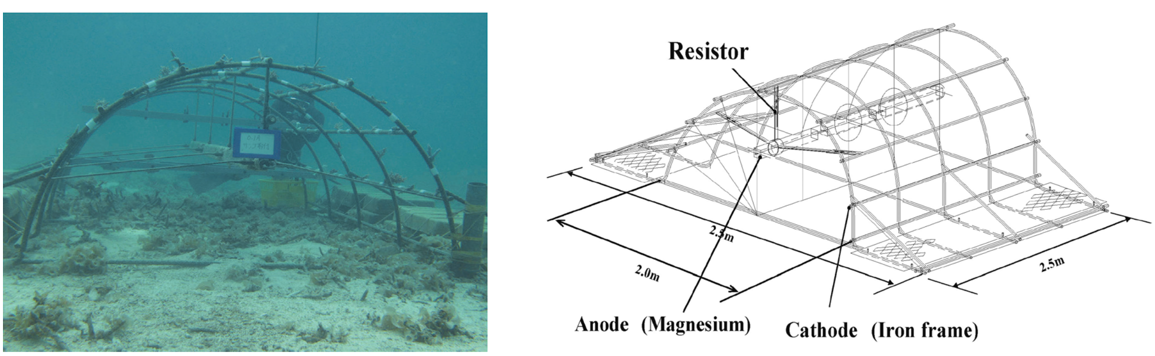


Fig. 3 Framework of the cage structure for the undersea experiment

range of those on the surface of pontoons (Fig. 2.)

Fragments of three common species in this area, i.e., *Acropora muricata* Linnaeus 1758, *Acropora tenuis* Dana 1846 and *Pocillopora damicornis* Linnaeus 1758, were attached with steel wire on the iron frame evenly in April 2007. The number of attached fragments was 20 for each species on each cage. The size of these fragments was 80–90 mm. Seasonal monitoring was conducted from April 2007 onwards; i.e. in August 2007, in January, June, October 2008, and in February, June, August, October 2009.

Results

During 3 years, growth of fragments on the structures fluctuated considerably, partly because of the abnormally high water temperatures in the summers of 2007 and 2008. Using the data from June 16, 2008 till February 21, 2009, we calculated the growth ratio (G) as the ratio of the increase in diameter of the coral fragments to the immediately preceding observation (such as; diameter in October 2008/that in June 2008 and diameter in February 2009/that in October 2008). In the present paper, we show only the result of *P. damicornis* that the data was most straightforward. The relationship between G value and the actual current density is shown in Fig. 4. Though plots are scattered around, data can be divided into 4 groups by the range of current density as; no current (0 mA/m^2), 20–50 mA/m^2, 50–100 mA/m^2 and over 100 mA/m^2. For the null case (0 mA/m^2), G value ranged from 100% (no growth) to 145%. The mean (G-mean) and standard deviation (sigma) were calculated as 126% and 16% respectively for G values of the null case (n=19). Sum of G-mean and 1sigma was 142%, as indicated with a dotted line in Fig. 4. For the other 3 fractions, the mean values and standard deviation of G values were; 126% and 14% (n=29) for 20–50 mA/m^2, 146% and 15% (n=10) for 50–100 mA/m^2, and 117% and 7% (n=20) for over 100 mA/m^2. Thus, the mean value (146%) for the 50–100 mA/m^2 fractions slightly exceeded 142% (the dotted line). The number of plots above the dotted line (142%), which represent faster growth of corals, was most abundant in the range of 50–100 mA/m^2. However, G values were always less than 142% for the current densities greater than 100 mA/m^2.

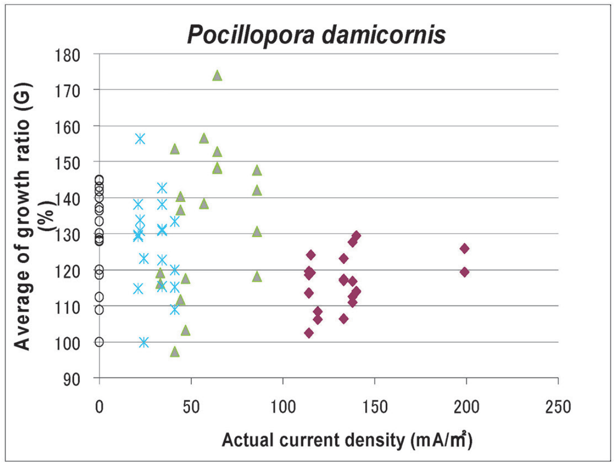
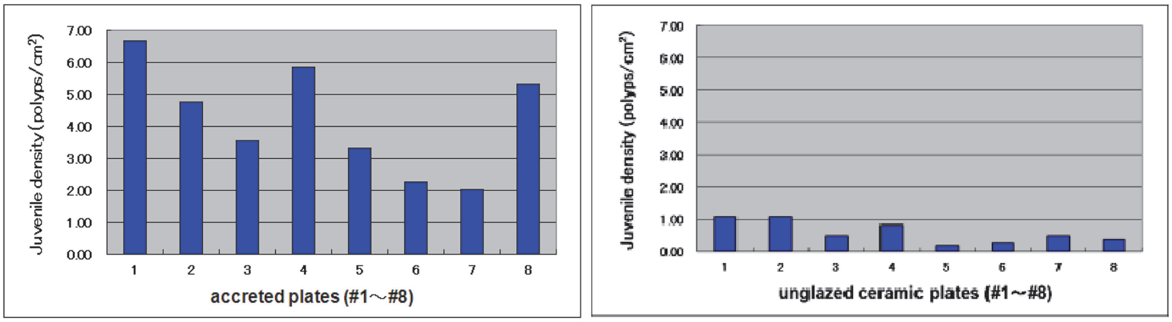


Fig. 4 Measured current density and growth ratio (G) for each colony of P. damicornis. (The dotted line shows G-mean + 1sigma value for Gs under null electric current density.)

Koibuchi et al. (2010) also showed that a weak current density affected to *A. muricata* similarly but to a less extent. The values of G for *A. tenuis* could not be recorded accurately due to damage caused by nibbling of fish on the coral fragments. Yap et al. (1992) suggested that *P. damicornis* shows a relatively high mortality rate when transplanting it, but adapts and grows well within a period of time after transplantation. So, the initial care and enhancement after transplantation may be especially important for this species.

Effectiveness of larval settling on mineral accreted substrates

Effects of substrate materials and electric current on larval settling were compared. Electrically mineral accreted plates were prepared for the comparison with unglazed ceramic plates (Taniguchi 2007). First, a number of wired mesh sheets (steel with mesh-openings of 2 mm) was accreted with a strong electric current density of 1000–2000 mA/m^2 for 30–60 days under seawater and then maintained within weak current densities of 10–100 mA/m^2 for 10–20 days. Thereafter, the plates were kept in seawater for more than 20 days until the laboratory experiment. Size of electrically accreted plates and unglazed ceramic plates was 10 cm × 10 cm.



a) accreted plates b) unglazed ceramic plates

Fig. 5 Number of coral polyps on the surface of settling plates under different current densities a): for accreted plates; b): for unglazed ceramic plates: plates #1 & #2, null current; #3 & #4, 10 mA/m^2; #5& #6, 50 mA/m^2; and #7 & #8, 100 mA/m^2)

In May 2009, cultured planula larvae of *A. tenuis* that had competence to settle on substrata were released into the seawater in an experiment tank for 72 hours, where one pair of the accreted plates and one pair of unglazed ceramic plates were immersed. Four different values of current density, i.e., 0, 10, 50, and 100 mA/m^2 were applied, and two pairs of the experimental plates (accreted plates and unglazed ceramic plates) were exposed to different current densities respectively. Numbers of polyps (juvenile corals) on the surface of experimental plates were counted after 5 days from the settlement using dissecting microscope. Results are shown in Fig. 5 a) and b), respectively. The number of polyps at different electric current varied, but it was always higher on the accreted plates than on the unglazed ceramic plates. Average number of corals on the 8 accreted plates (Fig. 5a) was 4.21 polyps/cm^2, whereas that of the unglazed ceramic plates (Fig. 5b) was 0.61 polyps/cm^2. Hence, the accreted plates had seven times more the number of juvenile corals than the unglazed ceramic plates.

Among the data set for the accreted plates, the density of polyps was highest for the null electric current (plates #1 and #2 in Fig. 5a). A similar tendency was found for the unglazed ceramic plates (plates #1 and #2 in Fig.5 b). Though statistical analysis can hardly be applied here because of the limited amount of data, it is clear that any of the electric current densities given during larval settling and immediate afterward were not effective.

Discussion

In some previous studies, effectiveness of electric field on growth of coral fragments and larval settlement on an iron-frame structure have been demonstrated using electric currents of several to 10 s A (Hilbertz and Goreau 1996; van Treeck and Schumacher 1997; Sabater and Yap 2002). Our results suggest that such a high current density may adversely affect the growth of corals. Also, application of electric current during larval settling is not effective.

Routine monitoring of the attached coral fragments for 3 years suggested that reef-building corals grew faster on the surface of the pontoon with the current densities of 10 mA/m^2 or more. The response of corals to the electric current may vary with species. Among the corals, *P. damicornis* appeared to show high response to higher electric current (Fig. 2), but the reason why growth ratio of *P. damicornis* decreased at the electric current densities over 100 mA/m^2 (Fig. 4) is unknown. One possible reason would be that extremely high pH or high alkalinity of sea water near the cathode hindered the growth of the fragments under higher current densities.

More study is necessary for the application of electrochemical method for propagation of reef-building corals. However, from our observations and experiments, it can be concluded that a weak electric current density below 100 mA/m^2 proved to enhance coral growth. We must be careful for the adverse effects of electrochemical application with high current density. The appropriate range of the electric current density for growth enhancement of coral fragments would be far below the conventional design values of accretion process.

Mineral accretion on the wire mesh appears to be favorable for larval settling. The accretion procedure here led to the formation of a specific substrate having unique quality and configuration. Under a high current density, $Mg(OH)_2$ (brucite) primarily precipitates; whereas under a low current, accretion of $CaCO_3$ (aragonite) dominant. The threshold value, at which both are equivalently precipitated, was found to be around 1000 mA/m^2 for the seawater in this region (Kihara et al. 2008). Our procedure aimed to enhance initial rapid formation of accreted layer and then deposition of $CaCO_3$ on the surface (Schuhmacher and Schillak 1994; Goreau and Hilbertz 1996; Schumacher et al. 2000). As above threshold value is 20–100 times higher than the observed current densities on the pontoon surface (Fig. 2), we applied weak current density for finishing the surface treatment.

In the comparison between the electrochemically accreted plates and unglazed ceramic plates, effect of the electric current (10–100 mA/m^2) during larval settlement and immediate afterward was not recognized. Instead, the accreted plates without electric current had seven times more the number of juvenile corals than the unglazed ceramic plates. The larval settlement was mostly enhanced not by the application of an electrical current, but by the previous deposition of calcium carbonate on the plates. Schumacher and Schillak (1994) also found in their experiment using electrochemical method that no organisms were found to settle on the substrate during the electrochemical process, and coral larvae settled and grew after 2 years when the electric current on their substrate approached zero. Very few studies have been conducted on the hydraulic effects on larval settling, but a small-scale configuration such as created surface asperity with small holes may result in the best trapping effect for coral larvae. We cannot conclude yet if this accretion procedure is optimal or most suitable, but the larvae settlement clearly showed more affinity for the accreted plates than the unglazed ceramic plates.

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