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Development of Restoration Technology for Coral Reefs Using "Marine Block^{TM}"†

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Abstract:

JFE Steel has developed restoration technology of damaged coral reefs using carbonated block, "Marine Block^{TM}." In Miyakojima in Okinawa Prefecture, the transplanted larva coral on "Marine Block^{TM}" had spawned eggs, and it was proved that this technology is well suited to coral reef restoration. Furthermore, this technology is currently on-site evaluation in the Republic of Indonesia, and the progress of this experimental project will be introduced in this paper.

1. Introduction

The development of a restoration technology for coral reefs using "Marine Block^{TM}"[1)] was reported in JFE Technical Report in 2009[2)].

Development of this technology is progressing smoothly. The results of tests at Miyakojima (Miyako Island), Okinawa Prefecture, Japan may be mentioned as an advanced example of research on coral reef restoration using a coral settlement device (CSD)[3)] which utilizes sexual reproduction of coral and "Marine Block^{TM}." In this example, successful results as a coral reef restoration technology have been obtained by research centering on Group of Tokyo University of Marine Science and Technology, JFE Steel, and others[4–6)]. Although not discussed in detail in the present paper, excellent results have also been obtained with "Marine Block^{TM}" as a base for restoration of seaweed beds[7)].

Coral reefs are distributed widely in tropical to subtropical marine areas, and are essential as the site of primary production in the ecosystems of those areas. For human life, they provide fishery resources and tourism resources, and at the same time, have a key function in protecting the land from natural threats such as typhoons and tsunamis[8)]. Today, however, coral reefs are decreasing rapidly around the world as a result of the influx of sediments from the land, explosive increases in *Acanthaster planci* (common name: crown-of-thorns starfish) and other natural predators, and damage caused by rising ocean temperatures accompanying global warming[9)].

In Japan, awareness of environmental preservation is continuing to increase as problems of this type become more widely known by the Japanese people. As a result, efforts to reduce CO_2 emissions and promote resource recycling have been implemented under the Basic Act on Establishing a Sound Material-Cycle Society and Law for the Promotion of Nature Restoration, and other initiatives, and preservation and restoration of the environment by effective utilization of resources and energy saving approaches are demanded by government agencies.

Against this backdrop, JFE Steel has begun tests of a coral reef restoration technology, not only in Japan but also overseas, using a combination of "Marine Block^{TM}," which is a carbonic solid of iron and steel slag that was established by JFE Steel as a CO_2 fixing technology using iron and steel slag, and a coral settlement device developed by Tokyo University of Marine Science and Technology and others. The results are reported in this paper.

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2. Outline of Study

A restoration technology for recovering previously-existing coral reefs was developed in a port district at Miyakojima in Okinawa Prefecture. At the development site, the sea bottom was covered with the remains of dead coral, and there was no matrix where coral larva could be implanted. Moreover, the standing stock of coral in the surrounding area had been diminished by coral bleaching due to the rising ocean temperature and predation by the *Acanthaster planci* starfish.

Because areas of this kind do not contain communities of coral whose branches can be broken, the matrix for planting coral is absent, and for this reason, restoration of coral reefs is difficult by existing techniques.

In response to these conditions, a technology for restoration of coral reefs was developed using "Marine Block™" as a base for transplanting coral, and a settlement device for securing young coral obtained by sexual reproduction.

The coral reef restoration area at Miyakojima had become a rock field which was covered with a thick accumulation of dead coral. Rock fields of this type are physically unstable, as the dead coral which has accumulated on the sea floor is constantly moved by ocean currents and may be washed away when a typhoon strikes. Deposits of floating mud as well as other life forms such as small seaweeds, which impede the growth of coral, tend to settle on dead coral, making natural growth of coral difficult in rock fields. In the rock field where this experiment was carried out, natural recovery of coral was not observed in the area surrounding the experiment site from the beginning of development of the technology.

However, based on the large accumulation of dead coral, it could be inferred that coral reefs had existed on a large scale in the past, indicating that the conditions for coral growth are present at this site.

Even assuming that coral for transplantation can be secured, a suitable seabed surface for transplantation does not exist at this site. In the development of this technology, the problem of a transplantation base was solved by using an artificial base "Marine Block™" which is suitable for coral growth.

The reasons for selecting "Marine Block™" as the artificial base were as follows (**Photo 1**):

- Is an energy saving material that can be produced using only slag, which is a byproduct of the steel manufacturing process and consists mainly of lime, and CO_2 as raw materials.
- Contributes to CO_2 reduction because CO_2 is absorbed (1–7 wt%) in the manufacturing process and fixed as $CaCO_3$.
- Has high biological affinity, as it has a covering layer consisting mainly of $CaCO_3$, which is the same chemical substance as shells and coral.
- Has high stability in water, as it is a porous block with porosity of 20–40%.
- Has no alkalinity effect on seawater, as chemical components are not eluted from the product.
- Has a fine rough surface where organisms can easily settle.

Photo 1 "Marine Block™" (left) and coral settlement devices (CSD)(right)

A coral larvae settlement test showed that "Marine Block™" has suitable quality for settlement of coral larvae, as the larvae implantation rate was approximately 2 times that of comparison concrete plates[10].

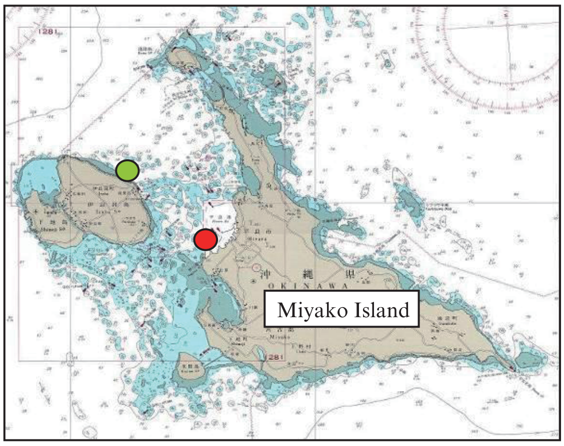
The field test method is outlined in (1) to (4) below.

(1) Installation of "Marine Block™"

The "Marine Block™" which were used as the coral transplantation base were deployed in a sea area at Miyakojima, Okinawa Prefecture (**Fig. 1**). The field test was conducted jointly with Tokyo University of Marine Science and Technology utilizing the marine experiment station provision system of Okinawa General Bureau.

(2) Installation of Settlement Devices

In order to secure coral for transplantation, settlement devices were installed in a sea area where it was considered that many coral larvae would be carried by the waters and settle on the devices during the



●: Location of "Marine Block™" installation
●: Location of coral settlement devices (CSD) installation

Fig. 1 Location of field test

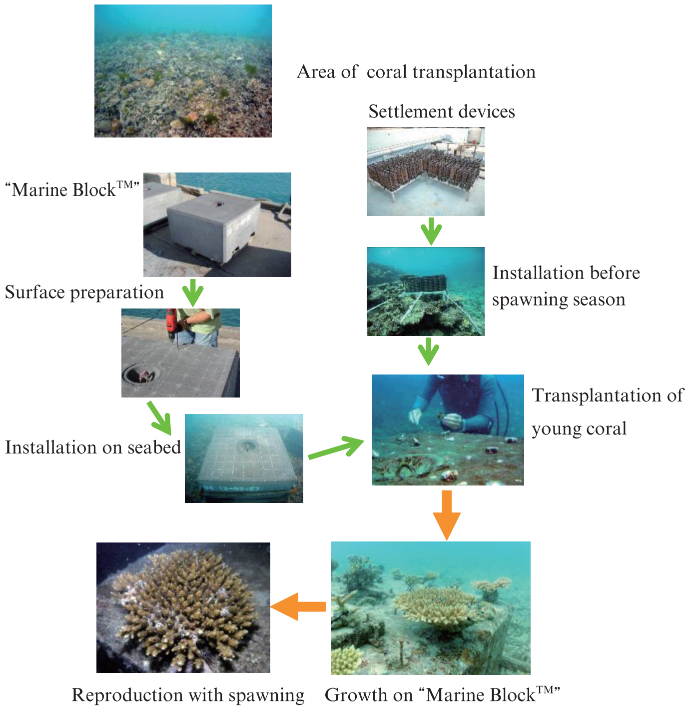


Fig. 2 Operation sequence

coral spawning season. This work was carried out each year beginning in 2005.

(3) Transplantation of Young Coral to "Marine Block™"

At the settlement devices which are installed during the coral spawning season, transplantation coral grow in a stock field. Coral larvae that settle on the settlement devices grow into young coral which are visible to the naked eye in about 1 year. Young coral were transplanted to the "Marine Block™" after growing to a size that could be seen clearly by the unaided eye. In research by Tokyo University of Marine Science and Technology, good yield was obtained when coral were transplanted after growing to a size of 5 cm or larger. However, 2 years or longer were necessary for growth to this size in the seas at Miyakojima, which has a subtropical climate[4–6].

(4) Operation Sequence

An image of the operation sequence of this technology is shown in **Fig. 2**.

3. Results

3.1 Seabed Condition and Transplanted Coral

Although the seabed condition has been a rock field for the entire time since the start of this research, the transplanted coral are growing, as shown in **Photo 2**.

3.2 Transplanted Coral and Gathering of Fish

The coral which were transplanted to the "Marine Block™" are growing steadily.

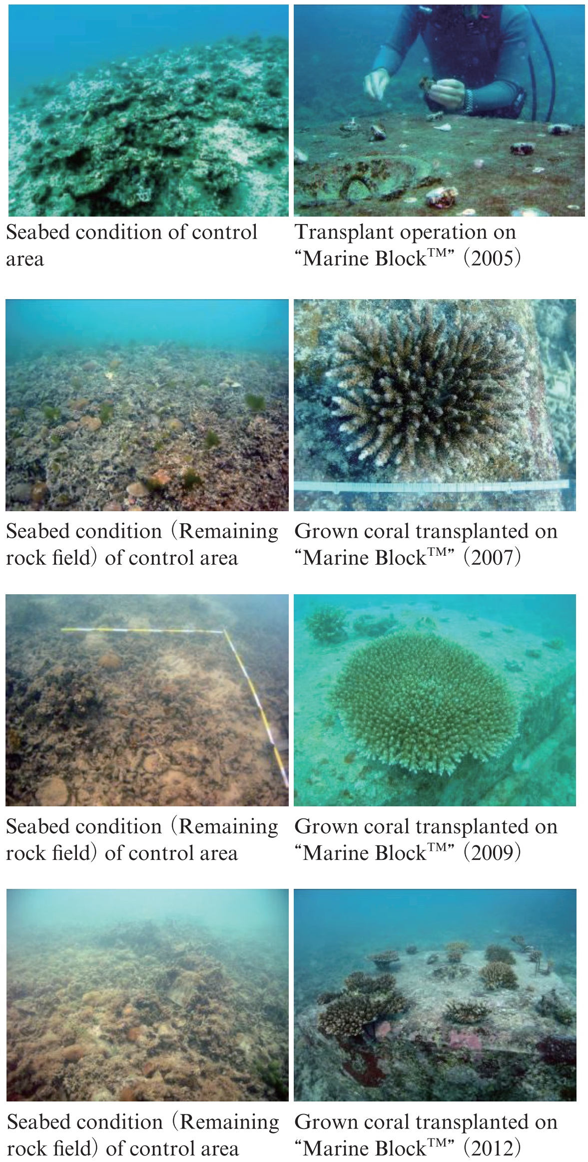


Photo 2 Control area and growth of coral on "Marine Block™"

Furthermore, as shown in **Photo 3**, when the coral has grown to a large size, it was also found that fish gather around the coral to use the coral as a hiding place and eat food adhering to the coral. Thus, this case showed that a lost natural ecosystem could be recovered by coral transplantation.

3.3 Condition of Growth of Transplanted Coral

Examples of the condition of growth of the transplanted coral are shown in **Fig. 3**.

In comparison with other corals, *Acropara sp.* grew quickly and, with time, attained a large size. On the other hand, the size of the *Pocillopara sp*. coral reached a peak after growth to a certain size, and this coral displayed a tendency to maintain its population while repeating a cycle of partial death and regeneration.

Acropara sp. is a typical coral of Miyakojima[4–6]. Although it is particularly important for the coral reef

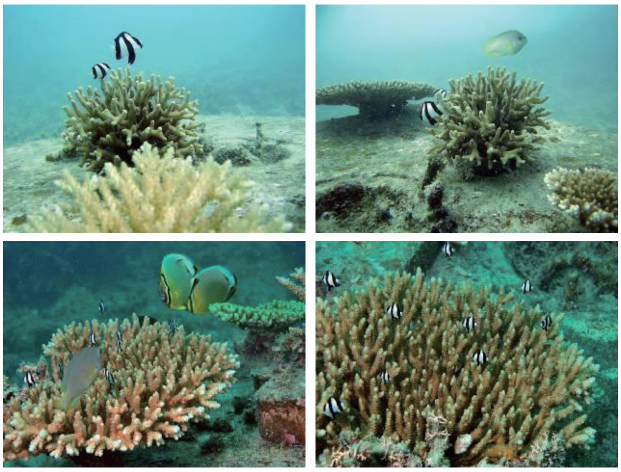


Photo 3　Fish gathering to "Marine Block™"

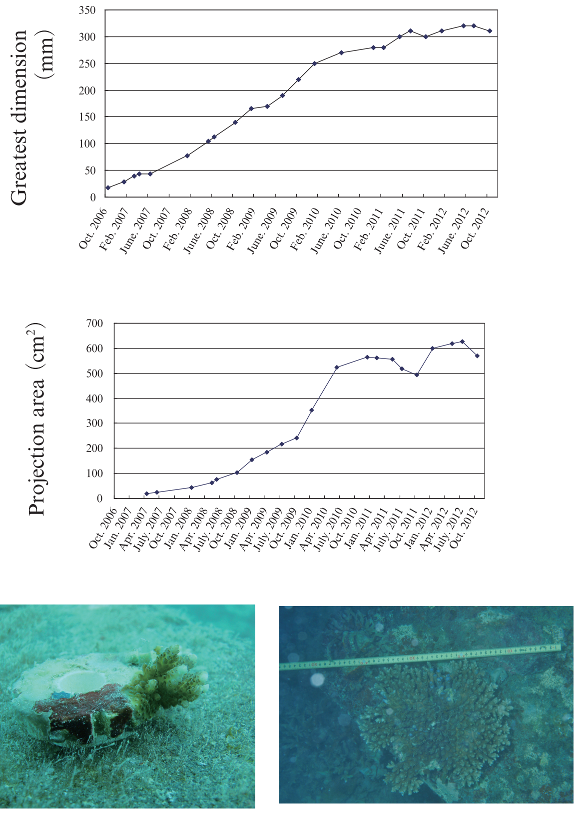


Fig. 3　Growth of *Acropora sp.*

ecosystem as a reef-building coral, its global decline is remarkable. Thus, restoration of the *Acropora sp.* coral is an urgent issue.

3.4 Reproduction from Transplanted Coral

In May 2011, spawning of the coral which had been transplanted to "Marine Block™" was confirmed. This coral is the coral shown in **Fig. 4**.

This species is *Acropora nasuta*. Seedlings were collected in May 2005 and transplanted to the "Marine Block™" in October. This species displayed the largest growth among the various transplanted corals. The max-

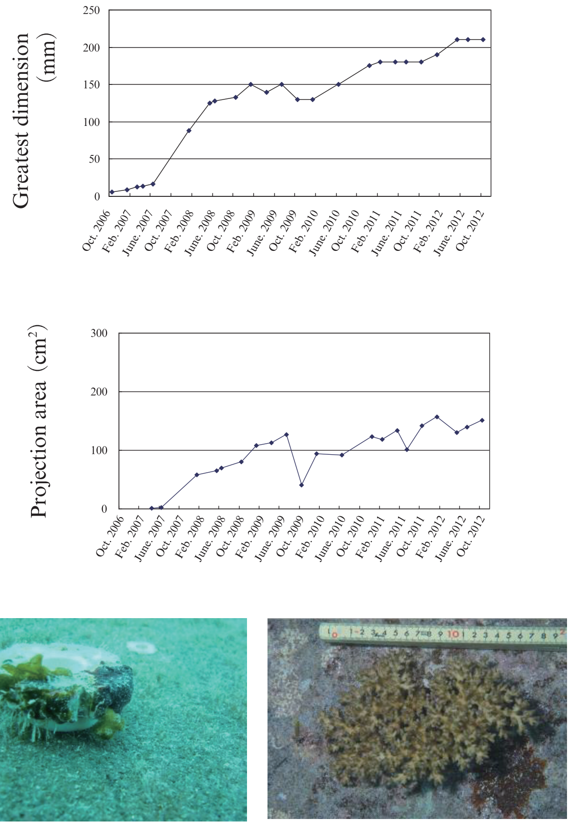


Fig. 4　Growth of *Pocillopora sp.*

imum size during spawning was 300 mm. Spawning was confirmed using an interval camera by photography at 1 min intervals at night (19:00-1:00 next day) during the period May 16–18.

Spawning of the coral began when bundles (capsule-like objects containing sperm and eggs) could be seen on the tips of polyps at 22:47 and 22:48 on May 17. (Polyps are animals with a sea anemone-like shape. Individual polyps are the basic unit of coral; what is normally called "coral" is a collection of these individuals, which inhabit the skeleton (corallum) of the coral.) From 22:49, bundles began to float upward from the polyps, and at 22:51, spawning ended temporarily with all the bundles detaching from the polyps. However, spawning resumed at 22:56, and then ended again at 22:56 (**Photo 4**).

The fact that spawning of the transplanted coral could be confirmed means that the reproduction cycle of the coral was completed at the transplantation site. In other words, it is possible to restore coral reefs, even in rock fields consisting of dead coral, by utilizing the proper techniques and materials.

The development of this technology is of great significance, as it enables restoration of coral reefs in locations where it has been impossible until now, under the present situation of rapidly decreasing coral reefs worldwide.

Thus, reproduction of coral on "Marine Blocks™"

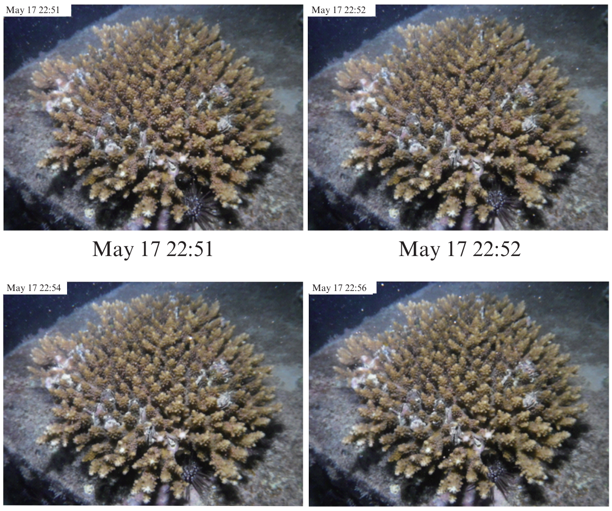


Photo 4 Spawning of transplanted *Acropora nasuta*

was successfully achieved in this experiment. At rock fields like that described above, the conditions are unsuitable for settlement and growth of coral larvae, in that the rock field is physically unstable and sediments, etc. have accumulated. If an area once becomes a rock field and the rock field is left as-is, as in the control area in this experiment (area without "Marine Blocks™"), coral reefs will not recover naturally. However, this experiment demonstrated that restoration of coral reefs is possible even in rock fields by installing a stable base for coral growth, namely, "Marine Block™," which is suitable for the growth of coral larvae.

4. Development to Other Countries

4.1 Background

Expansion of the technology developed as a result of this research to coral reef restoration projects throughout the world is possible.

Among actual results, as a research project, Ministry of Economy, Trade and Industry, Japan conducted a demonstration experiment for coral reef restoration in North Sulawesi Province in the Republic of Indonesia[11]. The location is shown in **Fig. 5**. This was reported at the meeting of the Working Group of the Economic Research Institute for ASEAN and East Asia (ERIA), which was established in June 2008[12].

4.2 Current Condition of Coral Reefs in North Sulawesi Province

The coral reefs in North Sulawesi Province have been damaged by blast or dynamite fishing, cyanide fishing, predation by the *Acanthaster planci* starfish, and other factors, and the condition of decline is progressing. The coral reefs in this region are also considered to

Fig. 5 Location of the experiment (Manado)

have been affected by the coral bleaching of 1998.

The condition of the coral in the Manado sea area was surveyed in the above-mentioned research project of Ministry of Economy, Trade and Industry[10] in 2010.

According to this survey, it was reported that a tendency toward high coverage by dead coral could be seen in locations with low coral coverage, and the health of the coral reefs in the Manado area was gradually being lost[10].

4.3 Purpose of Implementation

North Sulawesi Province in the Republic of Indonesia is an area with extensive developed coral reefs. In shallow seas from tropical to subtropical regions, coral reefs form the foundation of the ecosystem.

In particular, the seas of Indonesia are the center of the so-called Coral Triangle and necessary and indispensable for maintaining global biodiversity. The Coral Triangle contains approximately 30% of the world's coral and is a marine area of rich biodiversity, providing the habitat for more than 3 000 species of fish.

However, at COP10 (10th Conference of the Parties to the Convention on Biological Diversity), the Indonesian government noted that the threat to the coral reefs of Indonesia and the magnitude of lost economic value are both large, indicating that the situation has worsened to the point where the government stresses the importance of providing funds to support protection of coral reefs.

Simply accepting this status quo risks economic effects in the form of diminished tourism resources and fishery resources in the Republic of Indonesia.

The purpose of this test was to verify the applicability in Indonesia of the coral reef technology using "Marine Block™," which was developed in Japan.

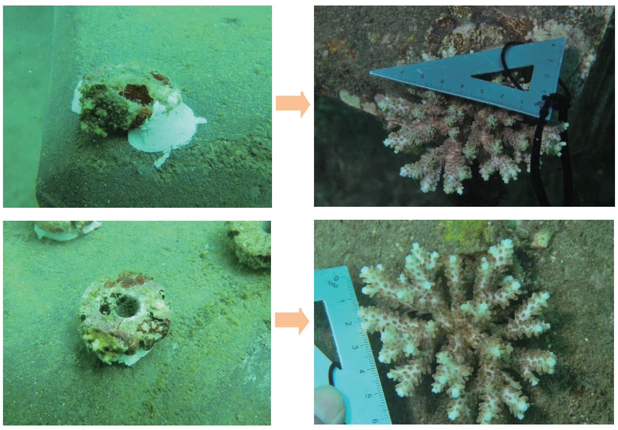
4.4 Outline of Experiment and Status of Monitoring

The coral reef restoration experiment in North Sulawesi Province was conducted as part of a research project of Ministry of Economy, Trade and Industry. At the site, 10 "Marine Blocks™" were installed at the location shown in Fig. 5.

In this experiment, a monitoring survey was carried out 1 month after coral transplantation, and a high initial survival rate of 93% was observed. On February 18, that is, about 3 months after transplantation, visual inspection was carried out for maintenance because accumulation of floating mud was feared, but due to the fast currents in the area, no floating mud was found. Furthermore, no natural decrease of the coral was observed. These results showed that "Marine Block™" can be used in the Republic of Indonesia as a base for coral growth.

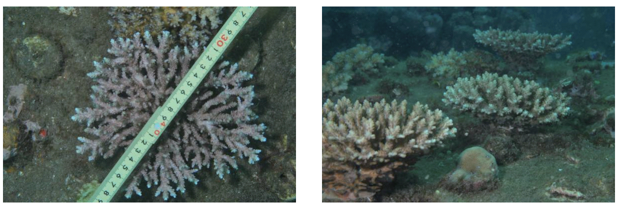
The young coral for transplantation were secured by natural settlement of coral larvae on settlement devices, by installing the settlement devices where it was thought that coral larvae would be carried by the waters and settle during the coral spawning period season. In transplantation of the young coral, "Marine Blocks™" were installed at a location where restoration had not progressed following bleaching, even though coral had been moved to that location in the past, with the aim of using the "Marine Blocks™" as a transplantation base.

In subsequent monitoring by Tokyo University of Marine Science and Technology and others, satisfactory growth of the young coral which had been transplanted to the "Marine Blocks™" was confirmed (**Photo 5, 6**). Although a detailed study is still in progress, the data show that the coral growth rate is faster than in Japan[13].



Nov. 2010 Photography   Sept. 2011 Photography

Photo 5 Growing *Acropora sp*. on "Marine Block™"



Aug. 2012 Photography   Aug. 2012 Photography

Photo 6 Growing *Acropora sp.* on "Marine Block™"

4.5 Expected Benefits

Maintaining healthy coral reefs will contribute to maintaining fishery resources and the development of the fishing industry, securing diversity in the marine environment, and the development of tourism.

(1) Maintenance of Fishery Resources and Development of Fishing Industry in Indonesia

Because the coral reef ecosystem is a good habitat for diverse forms of sea life, it forms the foundation of the coral reef fishing industry. Grouper, sea bream, and shrimp are fished from the coral reefs of North Sulawesi Province and used by residents.

However, catches in North Sulawesi Province show a remarkably decreasing tendency due to blast fishing and cyanide fishing. In recent years, the national and provincial governments have attempted to protect coral reefs by enacting strict regulations, but once a coral reef has been destroyed, considerable time is necessary for a reef to return to its original condition. Furthermore, conditions also exist in which coral reefs are destroyed and go extinct as a result of the above-mentioned fishing practices, and in such cases, the coral reef ecosystem does not recover.

In order to respond to the present condition, early restoration of coral reefs is desirable. Recovery and maintenance of marine resources can be foreseen as a result of coral reef restoration, and this will also contribute to activation of the regional economy. Thus, restoration of coral reefs has great significance for the residents of the surrounding area, and there is a high possibility that restoration will not only secure a source of food, but will also contribute to creating employment.

(2) Securing Biodiversity

The Republic of Indonesia is an island country with a rich natural environment, ranging from seas with coral reefs to mountains of 5 000 m class. It is one of the world's most important countries in terms of biological diversity. As it is also home to a high percentage of endemic species of plants and animals, it is a particularly valuable country from the viewpoint of valuableness.

According to the Indonesian Biodiversity Strategy and Action Plan (2006), a trial calculation of the economic value of the biodiversity in the coral reefs of the Republic of Indonesia valued these resources at US$567 million. Coral reefs have a high production capacity for bioresources and play a key role in fisheries, preservation of the marine ecosystem, etc.

Securing biological diversity is synonymous with high value, highlighting the significance of preserving and restoring coral reefs.

(3) Development of Tourism Industry

Focusing on the tourism industry of the Republic of Indonesia, because the country is made up of approximately 17 000 islands, including 5 main islands as well as medium-scale archipelagos, its beautiful scenery and diversity of animal and plant life have become tourism resources. Its extensive coral reefs are also among the world’s leading travel destinations and are used by tourist for diving and other forms of marine leisure. Although estimates of the area of the coral reefs in the Republic of Indonesia vary widely, from 7 500 km^2 (KLH 1992) to 85 707 km^2 (Tomascik et al. 1997), they are considered to comprise about 14% of the world’s coral reefs.

However, the coral reefs in this area are tending to decrease due to a variety of factors, and absolutely no tendency toward recovery can be seen. An early start of preservation and restoration of coral reefs will maintain an immense tourism resource and will contribute to the development of the tourism industry.

(4) Land Conservation

It is known that coral reefs have a breakwater effect that protects the life area of residents from natural threats. For example, in the tsunami that followed the giant earthquake off Indonesia’s Sumatra Island in December 2004, it has been reported that damage was reduced in areas where coral reefs grow[14)]. This is because the depth of coral reefs is shallow and thus reduces the speed of tsunamis, and at the same time, coral reefs have a wave-breaking effect that diminishes the energy of tsunamis.

As this example shows, preservation and restoration of coral reefs is also an important factor from the viewpoint of national land conservation.

4.6 Dissemination of Results

In carrying out the local model tests, the Japanese side, together with the Faculty of Fisheries and Marines, Sam Ratulangi University (Manado, Indonesia) as the counterpart organization, constructed a network which also included North Sulawesi Province and the related agencies of the central government.

Because smooth results were shown by coral reef restoration efforts at Likupan Village in North Sulawesi, interest among those concerned at local universities and in the government is continuing to rise. In 2012, a memorandum for smooth promotion of a study and information exchanges on protection of the natural environment in North Sulawesi Province was exchanged with persons involved in coral reef restoration in Likupan.

At the meeting of the ERIA Working Group in April 2011, coral reef restoration efforts attracted much interest from the participating countries.

Based on the environmental test results, an international symposium on artificial reefs was held in Manado, North Sulawesi Province on February 16, 2011, sponsored by Sam Ratulangi University.

Creation of a network with specialists who are actually interested in coral reef restoration, by sharing the results of effective utilization, has been mentioned as a target. Exchanges were possible at the above-mentioned symposium, where Sam Ratulangi University, related local persons, and Tokyo University of Marine Science and Technology participated.

The results of this research were announced at the 12th International Coral Reef Symposium (International Society for Reef Studies) in July 2012[15)], and attracted global interest as advanced efforts in connection with coral reef restoration.

5. Conclusion

In the development of a coral reef restoration technology using a combination of JFE Steel’s “Marine Block™” and a coral settlement device at Miyakojima, the effectiveness of a technique utilizing sexual reproduction of coral was successfully demonstrated. The fact that spawning of the transplanted coral was observed, confirming that coral enter the reproductive cycle when this technology is used, is also considered to be of great significance.

Because coral reefs are widely distributed in tropical and subtropical seas, the developed technology is applicable to a wide range of geographic areas.

Since 2010, efforts to restore coral reefs using this technology have been carried out in North Sulawesi Province of the Republic of Indonesia, and satisfactory results have been successfully obtained.

In light of the current situation, in which 85% of the coral reefs in the Coral Triangle are in danger of extinction[16)], a program called the Coral Triangle Initiative (CTI)[17)] has been launched, heightening the opportunities for sustainable management and protection of coral reefs.

In the future, JFE Steel will continue to contribute to national land conservation and preservation of the natural environment, beginning with ecosystems, through effective utilization of byproduct iron and steel slag.

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