UDC 669 . 295 : 624 : 629 . 12

Application of Titanium to Construction, Civil Engineering and Ocean Development


Kinichi KIMURA*1


Kazuhiro KINOSHITA*1


Kiyonori TOKUNO*1


Hiroshi SHIMIZU*1

Abstract

Nippon Steel is exerting efforts to open up new applications for titanium, such as its uses as a material for buildings, civil engineering and ships, and other marine structures. In the building materials field, the company has realized various surface finishes to meet the diverse needs of its customers. In the civil engineering area, it has developed techniques for lining structures with titanium-clad steel sheets. Recently, the company has applied titanium to the pontoons of a floating bridge linking Yumeshima and Maishima Islands in the Port of Osaka. In other marine applications, Nippon Steel has produced all-titanium ships, spurring interest in the wider use of titanium in shipbuilding.

1. Introduction

Titanium and especially commercially pure titanium are used in chemical and power plants thanks to their excellent corrosion resistance. Recently, titanium has come to be used in familiar products like eyeglasses and golf clubs. It is also used as building material. Architectural titanium was initially used in roofs and walls by reason of its corrosion resistance. As its demand has increased, it has been increasingly required to provide appropriate surface appearance as well. Nippon Steel has developed a variety of surface finishes to meet the needs of its architectural titanium customers.

In the civil engineering industry, the design philosophy is changing from consideration of steel corrosion allowance to maintenance-free corrosion protection. There have appeared cases in which titanium is utilized for corrosion protection. A basic corrosion protection (or prevention) method covers a steel structure with titanium. Since titanium cannot be welded to steel, Nippon Steel has developed corrosion protection methods using titanium for long periods of successful service.

Titanium has almost absolute corrosion resistance in sea water. From a corrosion resistance point of view, titanium is considered to be the optimum material of construction for ships, but it is generally used little to build ships, although it is reported to have been used in some naval vessels. Nippon Steel completed all-titanium ships in cooperation with shipbuilders to the attention of those concerned.

Here are described the applications of titanium in the building, civil engineering, offshore, and shipbuilding industries.

2. Building Materials

2.1 Demand for titanium as building materials and reasons for its adoption as building materials

Since the first use of titanium as building material 27 years ago, the consumption of architectural titanium has been steadily growing in the last decade despite experiencing some ups and downs along

*1 Titanium Division

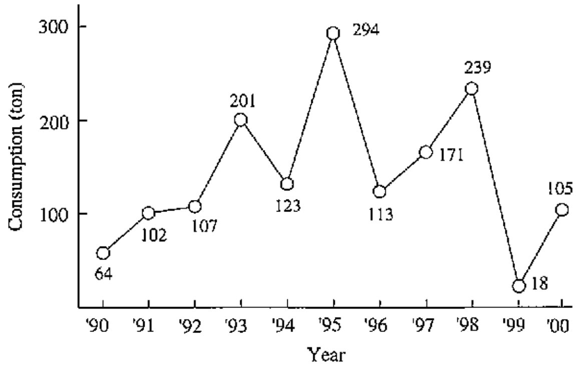


Fig. 1 Change in consumption of titanium as building material from 1990 to 1999 (on as-completed basis)

the way, as is illustrated in **Fig. 1**[1]. From 1993 to 1995, titanium was adopted in large construction projects, such as the Fukuoka Dome (1993, 120 tons), Tokyo Metropolitan Expressway ventilating tower (1994, 68 tons), Tokyo Big Sight (1995, 140 tons), and Marine Messe Fukuoka (1995, 60 tons). In 1996 and 1997, there were no such large projects, but titanium was used in amounts of 113 and 117 tons, respectively, in many smaller projects. In 1998, titanium was used in the Shimane Art Museum (60 tons), Showa Hall (57 tons, **Photo 1**) in Tokyo, and Yokoshi Tomonokai, Suza, a religious group (20 tons). The consumption of architectural titanium declined in 1999, but picked up in 2000 with the construction of the Oita Stadium (80 tons), for example. Thus, the application of titanium in the building industry appears to have taken root in this way.

The titanium use proportion by application from 1986 to 1997 was 64% for roofs, 30% for exterior walls, and the rest for monuments and the like. Titanium is used mostly in roofs[1].

Titanium has outstanding corrosion resistance in punishing corrosion environments in nature. When architectural projects executed using titanium as building material were investigated and classified by reason for adoption of titanium in 2000, corrosion resistance was cited for 51% of the projects, followed by aesthetic surface appearance for 43% and light weight for 6%. The projects that cited corrosion resistance as the reason for adoption of titanium overwhelmed the others[1]. Titanium has corrosion resistance by far higher than that of other building materials in coastal and volcanic mountain regions and more recently in acid rain regions. Among examples of titanium applications to coastal structures are the Okinawa Prefectural Budokan (1997, 23 tons) and the Bulbous Observation Room of the Headquarters Building of Fuji Television Network in Odaiba, Tokyo (1996, 14 tons). Examples of the use of titanium in a volcanic mountain regions, there are the Kagoshima Prefectural Office Building (1995 and 1996, 70 tons). Acid rain is beginning to damage historical cultural assets like temples and shrines. For protection against such phenomenon, titanium was adopted in the roofs of the Ikkyuji (1992, 1 ton) and the Kitano Tenmangu (1998, 4 tons, **Photo 2**).

In 1997, titanium was adopted in the Heisei Hall at the Tokyo National Museum (18 tons) and in the Nara National Museum (13 tons), both built to last 100 years.

Building projects that cite esthetic surface appearance and titanium image as reasons for adoption of titanium are increasing in number. Titanium in its natural surface state, and colored or aluminum shot blasted titanium have come to be preferred. Titanium must meet the requirements of increasing severity not only for corrosion resistance but also for surface appearance.

2.2 Surface appearance of architectural titanium sheet

The exceptional corrosion resistance of titanium is attributable to its natural surface finish. Titanium needs no special surface treatment for corrosion protection. When titanium was first used as building material, its surface was sometimes not specially controlled for the architectural application.

As its architectural demand has increased, aesthetic surface appearance has been required of titanium more heavily than in the past. Titanium manufacturers have been researching and developing titanium products to meet the requirements. Nippon Steel has developed and commercialized the following surface finish methods for architectural titanium.

1) Roll dull finish

In skin pass and other rolling operations, dull rolls are used to transfer the roll surface pattern to the surface of titanium. Roll dull-finished titanium has a relatively lustrous surface. It was used in such buildings as the Bulbous Observation Room of the Headquarters Building of Fuji Television Network (already mentioned), Okinawa Prefectural Budokan (already mentioned), and Osaka City Minato Ward Sports Center (1995, 21 tons).

2) Combination of roll dull finish and acid pickling

The above-mentioned dull finish method is combined with the method of pickling in nitric-hydrofluoric acid, for example, so that a metallic color characteristic of titanium can be reproduced in white. In recent years, titanium sheets surface finished by this combination have been used in many large construction projects, including the Mie Prefectural College of Nursing (1997, 30 tons), Shimane Art Museum (1998, 60 tons) and Yokoshi Tomonokai, Suza (1998, 30 tons).

3) Aluminum shot blast finish

Aluminum shot blast finished titanium is Nippon Steel's original titanium sheet product whose surface is dull finished with aluminum shot. The aluminum shot blast finished surface has a relatively low gloss and is grayish in color. This type of architectural titanium was used in such construction projects as the Ikkyuji (already mentioned), Heisei Hall at the Tokyo National Museum (1997, 18 tons), and Showa Hall (1998, 57 tons).

4) Colored finish

In addition to the aforementioned titanium surface finish methods, there is the anodic oxidation method of producing sharp red and gold colors that can be obtained only with titanium. Titanium colored vividly blue by this method was used in the interior of the clubhouse of the Hanayashiki Golf Course in Osaka (1993, 5 tons) and of a cafeteria in the building of Conde Nasta in New York (1998, 5 tons).

In place of patina-colored copper, titanium provided with a green color resembling the patina color of copper after aluminum shot blasting is used in the acid rain-damaged roofs of temples and shrines, including the temples Daitokuji and Kobaiin (1996, 2 tons) and the Kitano Tenmangu (1998, 4 tons) in Kyoto. Titanium colored brown (COR-TEN color) after aluminum shot blasting was used to match the color of the COR-TEN steel sheet roof of the existing building of the Nara National Museum.

As a result of the development effort made by titanium manufacturers to meet a variety of market needs, surface finishes peculiar to titanium, such as aluminum shot blast finish and colored finish, have been added to acid pickled dull finish and other conventional surface finishes like those of stainless steel. Titanium can now be produced with a rich variety of surface finishes.

2.3 Architectural titanium for protection of valuable historical cultural assets

The pH (hydrogen ion concentration) of water in equilibrium with the carbon dioxide concentration (about 350 ppm) in air is about 5.6. Rain of lower pH is called acid rain. It is reported that valuable historical cultural heritages like the Pantheon Temple in Greece are damaged by acid rain[2]. In Japan, the 0.5-mm copper sheet used in valley gutters in the roof of the Koetsuji in Kita Ward, Kyoto, was perforated by corrosion after 16 years of use[3]. When the actual situation of acid rain was investigated, it was found that rain of about pH 4 actually falls in the Kyoto region and contains a large amount of SO_4^{2-}[4]. This type of acid rain is believed to have started attacking the copper sheet roofs of cultural assets like temples and shrines.

When titanium and copper were simulative corrosion tested using synthetic acid rain, titanium developed no corrosion at all, but copper corroded[5]. Titanium building materials are completely free from such problems as copper ion run-out, suited for the preservation of valuable cultural assets to be handed down to posterity, and noticeable on Japanese-style buildings because they match the historical landscape represented by such Japanese-style buildings.

One architectural titanium problem that has recently come into spotlight is its change in color from initial silver to brown in a few years after construction. This is not a functional problem like the corrosion or perforation of titanium.

Nippon Steel analyzed exposure test specimens and actual construction materials with different degrees of this discoloration in detail for chemical composition and mechanical properties, among other factors. A method was also established for quantitatively evaluating the degree of discoloration. It consequently became possible to evaluate whether or not materials would discolor in service in a short time in the laboratory, instead of long time of exposure test. In other words, the presence or absence of discoloration was formerly evaluated by a few years of exposure test. It then became possible to complete this evaluation in a few weeks and to quantitatively relate the degree of discoloration to manufacturing conditions and to clarify the factors that affect the discoloration of titanium. These results enabled us to develop titanium less susceptible to discoloration. Nippon Steel's titanium with excellent discoloration resistance is already used in the roof of a main stadium in a sports park in Oita (**Photo 3**).

In the case of architectural titanium, importance is also attached to the uniformity of appearance as a building. If the roof and other exterior panels of the building partly differ in surface color, the entire appearance of the building suffers. Most buildings are too large to cover with one lot (coil) of titanium. Two or more lots (coils) must be used for such buildings. Even if their manufacturing conditions from hot rolling through cold rolling to product are controlled, different coils may differ in surface quality, though very slightly. For this likelihood, Nippon Steel thoroughly controls each lot. When its titanium is used in an actual building, Nippon Steel informs the fabricator of the construction position of each lot. The titanium surface appearance uniformity of the entire building is ensured in this way.

3. Titanium Applications in Offshore Sector

3.1 Offshore structures

Offshore steel structures had no idea of corrosion protection about 40 years ago and were designed with steel corrosion allowance. The corrosion allowance idea still remains. In the "Port Structure Corrosion Protection and Repair Manual"[6] revised by the Coastal Development Institute of Technology in 1997, the corrosion allowance idea is abolished, and implementation of some corrosion protection method is recommended. This agrees with the guideline[7] of the Ministry of Construction for minimizing the maintenance cost to leave no negative assets to posterity. The trends of the times are toward the construction of load bearing members with low-cost steel and corrosion protection (or prevention) of the steel members by some method to ensure the long service life of the offshore structure. It is needless to say that titanium application methods are expected to assure the longest possible service life. Covering with titanium-clad steel sheet and covering with titanium sheet are developed as corrosion protection methods using titanium.

The former method directly welds titanium-clad steel sheet to steel structures and is expected to provide about 100 years of service. The latter covers steel pipe piles with titanium sheet. Existing steel pipe piles may be covered with titanium sheet, or new steel pipe piles may be covered with titanium sheet before installation.

3.2 Corrosion protection by covering with titanium-clad steel sheet

For large offshore steel structures expected to last a very long period of time, corrosion protection near their tidal zone was the most difficult corrosion protection problem. The titanium-clad steel covering method solved the problem and at the same time prolonged the service life of offshore steel structures. This corrosion protection method was adopted for the first time in the splash and tidal zones of the piers of the Trans-Tokyo Bay (TTB) Highway (also called Aqua-Line) (**Photo 4(a)**)[8, 9]. It was next applied to the corrosion protection of steel-concrete hybrid structures, including the Monbetsu Sea Ice Observation Tower (**Photo 4(b)**)[10]. Titanium-clad steel was then used for the corrosion protection of floating structures in the research of the Technological Research Association of Mega-Float[11].

Titanium-clad steel covering work was executed on the bridge to connect Yumeshima and Maishima under construction at a tract of reclaimed land in the Osaka Bay from November 1998 to February 1999. The bridge is the world's first floating bridge with piers erected on two pontoon foundations and girders then connected. The two pontoons are covered with titanium-clad steel sheet in the submerged zone. The basic structure is the same as applied to the piers of the Trans-Tokyo Bay Highway described earlier.

3.3 Corrosion protection by covering with titanium sheet

3.3.1 Corrosion protection of existing steel pipe piles

The corrosion protection method of covering the petrolatum coating of existing steel pipe piles with about 0.5 mm thick titanium sheet had been under development since About 15 years ago. Conventional corrosion protection methods included underwater painting, mortar coating, and the combination of petrolatum coating and FRP covering. None provided sufficient durability. Material deterioration can be cited as the reason for this poor durability. The deterioration of FRP rather than petrolatum was responsible for the petrolatum coating-FRP covering combination. The petrolatum coating-titanium sheet structure, the covering to protect from corrosion,installed at Nippon Steel's Nagoya Works in 1985 was dismantled and investigated in 1995. No deterioration was found at all in the petrolatum coating, let alone the titanium sheet covering. These good results[12] were probably attributable to the protection by the titanium sheet covering of the petrolatum coating against ultraviolet degradation. Based on the results, the application of this corrosion protection method has been expanding yearly.

3.3.2 Steel pipe piles covered with titanium sheet at mill

Resin-coated steel pipe piles are commercialized as corrosion-protected steel pipe piles. None of them are strong or durable enough, however. Corrosion-protected steel pipe piles that are covered with titanium sheets at a mill are under development.

4. Titanium Applications to Ships

The former Soviet Union is believed to have led other countries in the application of titanium in ships, but the details of this mainly military application are not clear. The application of titanium to ships in Japan is hereinafter described. All-titanium ships were built earlier than generally considered. An all-titanium yacht, christened "Marishitan", was built[13] in 1985. Regrettably, a second all-titanium ship was not built until about three years ago when Eto Shipbuilding in Karatsu, Kyushu, decided on the construction of all-titanium ships, mastered the titanium welding techniques required, and built two all-titanium fishing vessels. These all-titanium ships kindled the interest of the shipbuilding industry in titanium. A titanium ship working group was organized within the Japan Titanium Society last year, which has been studying the possibility of expanding into the shipbuilding industry since then. Amid these movements, some shipyards started using titanium in peripheral members and have already attained titanium applications therein.

The all-titanium ships built to date are two yachts, "Marishitan" and "Titan Lady", and two finishing boats, "Second Asahimaru" (**Photo 5**) and "Akimaru". The last three ships are 12 to 14 m in length, are less than 5 tons in displacement, and passed the safety inspection of the Japan Craft Inspection Organization (JCI) as an official inspection for ships of this class.

The purposes of using titanium in peripheral members are corrosion resistance and weight reduction. Among such members made from titanium are exhaust cooling pipes and mufflers (corrosion resistance), fire-fighting sea water guide pipes and valves (corrosion resistance), ladders and shaft brackets (weight reduction), and propellers and shafts (corrosion resistance and weight reduction). These parts are small in amounts and relatively young in their service performance.

5. Future Outlook

The aforementioned titanium applications to buildings, civil engineering structures, and ships are all examples that are found in Japan.

As building material, about 80 tons of titanium was used in the exterior walls of the Guggenheim Museum in Bilbao, Spain, in 1997. This project drew attention to titanium overseas as well. Amid the present construction demand slump in Japan, there have been few large construction projects since the Oita Stadium (80 tons). Demand for architectural titanium can be expected abroad.

In the civil engineering sector, titanium is still used in only a few limited applications. This is probably because users have such false information that titanium is expensive and difficult to fabricate. This information shortage of users should be corrected through publicity activities of the Japan Titanium Society and other titanium-related organizations, so that more users can pursue the possibility of titanium applications. Titanium manufacturers must of curse work to lower the price of titanium materials. Since ships especially require many weld joints, the development of methods for fabricating and welding titanium, such as MIG welding, is necessary. It is expected that these efforts will be combined to guarantee growing demand for titanium in the offshore industry where titanium is best suited by definition.

References

1) Yamamoto, Y.: Titanium. 49 (3), 98 (2001)
2) Komeji, T.: Zairyo-to-Kankyo. 41, 118 (1992)
3) Kihira, H., Matsuhashi, T., Soeda, S., Tagomori, N., Kinoshita, K.: Proceedings of the 42nd Corrosion Engineering Corocium. 1995, p.23
4) Tagomori, N., Kihira, H., Kinoshita, K., Nakamura, T., Soeda, S.: Proceedings of Corrosion Engineering. 1994
5) Takahashi, Y., Tadokoro, H., Muto, I., Tagomori, N., Hitoshi, S.: Nippon Steel Technical Report. (352), 9 (1994)
6) Corrosion of Structures at Port. Repair Manual (revised). (Juridical Foundation) Coastal Development Institute of Technology, 1997
7) The Outline of the Budget Demand for R&D of Construction Technology for Year 1996. The Ministry of Construction, 1993
8) Kagawa, Y. et al.: Technical Papers, Japan Society of Civil Engineers. (435), VI-15 (1991)
9) Tadokoro, H. et al.: Nippon Steel Technical Report. (344), (1992)
10) Sato, K. et al.: Marine Voice21. 195, (1997)
11) Matsuoka, K. et al.: Zairyo-to-Kankyo. 47 (8), (1998)
12) Kinoshita, K. et al.: Corrosion Control. 41 (12), (1997)
13) Kotaki, H.: Titanium. 48 (1), (2000)

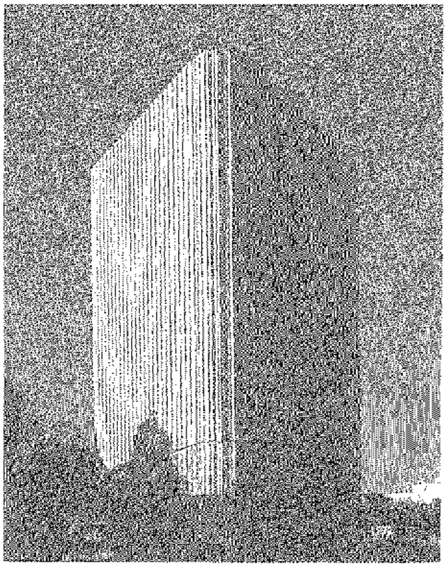


Photo 1 Titanium building material (aluminum shot blast finished) with unique surface appearance: Exterior walls of Showa Hall in Kudanshita, Tokyo

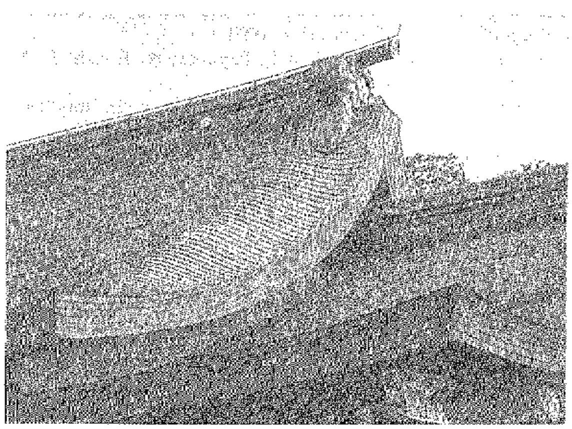


Photo 2 Titanium building material (aluminum shot blast finished and green colored) to protect valuable cultural asset: Roof of Treasury of Kitano Tenmangu in Kamigyo Ward, Kyoto

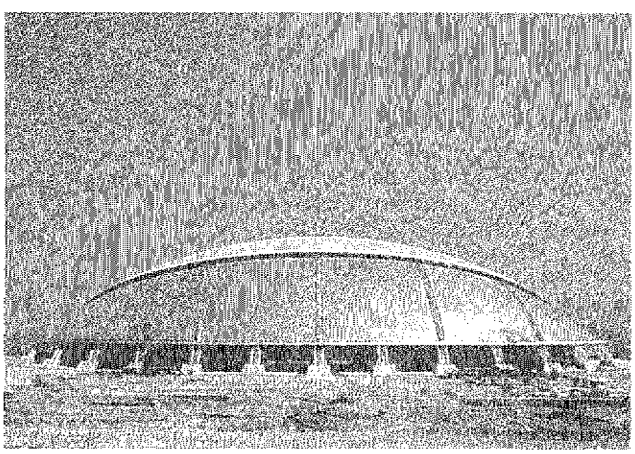
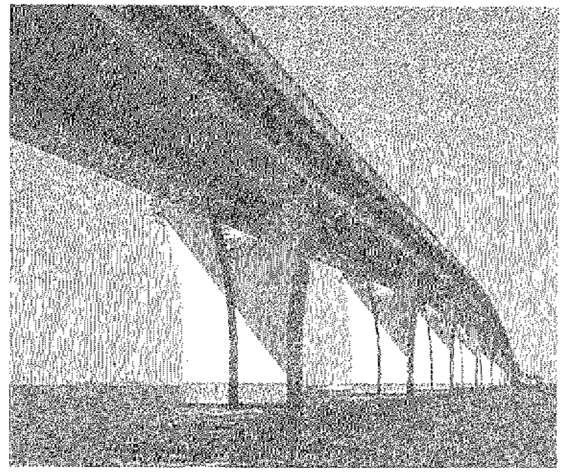
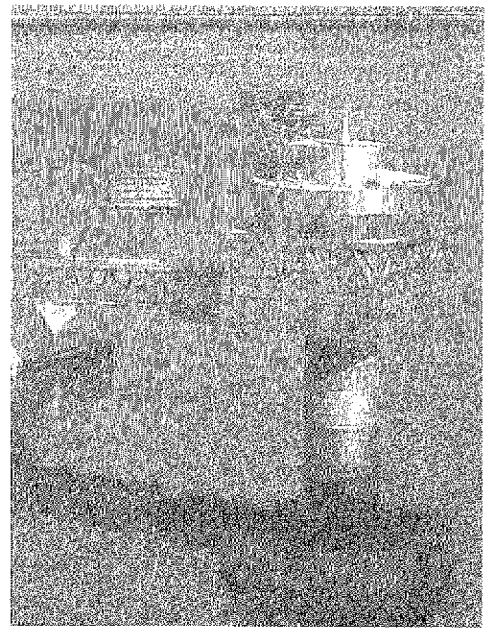


Photo 3 Oita Stadium



(a) Piers of Trans-Tokyo Bay Highway (Aqua Line)



(b) Monbetsu Sea Ice Observation Tower

Photo 4 Titanium-clad steel sheet used for very long corrosion protection of offshore steel structures

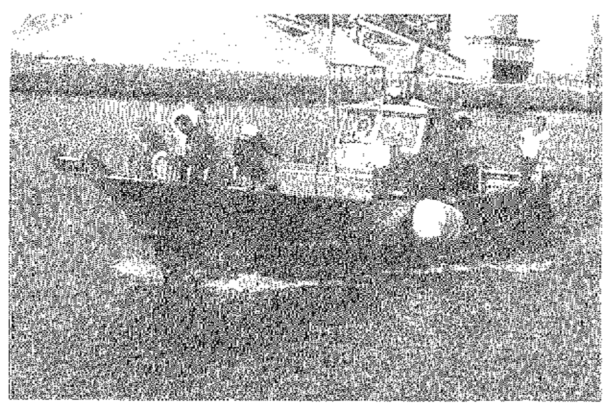


Photo 5 Small ship entirely built of titanium, launched in Karatsu City, Saga Prefecture, in 1998