NIPPON STEEL

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Features of Titanium Building Materials
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NIPPON STEEL

Titanium

Features of Titanium Building Materials

NIPPON STEEL CORPORATION

Titanium, on the cutting edge of the times, is an environmentally friendly metal.

Titanium, an element found in 1790, was named after the Titans, earth giants in ancient Greek mythology.

Its industrial production began in around 1946. Being “light,” “strong” and “rust-free,” it began to be applied in the aerospace, chemical, electric-power and other industries, finding its way further into architectural, civil-engineering and general-purpose applications.

Architects began to use titanium in the 1970s. Titanium’s unparalleled performance in corrosion-resistance makes many architectural designs possible for structures in severely corrosive, salty atmospheres of seashores and also in permanent architecture (e.g., museums, temples and shrines). Lately, titanium designs have begun to spread to general housing also.

Overseas, in the 1990s, the use of titanium on a massive scale by Frank O. Gehry in the Guggenheim Museum (Spain) attracted the attention of many modern architects and spread to many countries. Demand for titanium building materials is expected to further grow in the future.

CONTENTS

Development of titanium building materials

Titanium building materials which have come into the world as building materials with superior corrosion resistance to stainless steel and copper are the focus of attention among many architects because of their design properties. NIPPON STEEL has been engaged in various technological developments necessary for producing architectural design materials.

Features of titanium building materials

We continuously strive to enable titanium to maintain its design properties coherently, from design selection, through forming and installation, to maintenance.

1. *Page 2~*

Basic characteristics of titanium building materials

Titanium offers superb properties as a building material which is ideally suited to application in a highly corrosive environment.

2. *Page 6~*

An extensive product menu (Surface finish)

We developed titanium materials with a wide variety of surface finishes, from those that look like tiles and are suitable for Japanese temples and shrines, to lustrous, colored materials that are suitable for modern architecture.

3. *Page 10~*

Development of titanium that does not readily become discolored(Note)

We developed titanium materials for building use that do not easily become discolored with the passage of time.

4. *Page 13*

Reduction of color-tone from one lot to another

With metal, the color-tone from one lot to another poses an issue from the design aspect. We developed control technology that enables a large area to be produced with relatively little color variation.

5.

A wealth of application technology

- Development of a material that has little distortion during forming *(Page 14)*
- Development of a suitable cleaning agent *(Page 15)*

(Note) This product reduces the rate of discoloration with the passage of time. It does not stop discoloration. It is not possible to guarantee that discoloration will not occur.

1. Basic characteristics of titanium building materials

1. Unparalleled corrosion resistance

Titanium, readily forming stable oxide films (in a passive state), gives excellent performance in corrosion resistance. In ordinary service environments of building materials, the possibility of titanium building materials becoming corroded is non-existent.

(1) Seawater corrosion resistance is comparable to that of platinum
— suited to application in coastal areas.
(2) Excellent corrosion resistance to corrosive gases (sulfurous acid gas, hydrogen sulfide gas, etc.)
— suited to application in large cities, industrial areas, hot-spring resorts and the like. Titanium is a metal that also resists such environmental pollution as acid rain.
(3) Titanium is quite free of stress, pitting, and crevice corrosion as well as other types of corrosion or problems inherent in stainless steel.
(4) Corrosion due to contact with different metals (Refer to “Corrosion potential in sea water” on page 21)
The corrosion potential of titanium is virtually equal to that of stainless steel, and it can be used in the same manner. In locations where protection against contact corrosion is paramount, consideration must be given to insulation and the prevention of condensation.

Table 1. Comparison of weather resistance between various metals
(Source: Japan Titanium Society)

	Titanium	Stainless steel SUS 304	Copper
Sea salt particle resistance (pitting)	◎	△	○
Ultraviolet ray resistance	◎	◎	◎
Acid rain resistance (pitting)	◎	△	△
Acid rain atmospheric resistance	◎	△	×
Contact corrosion resistance*	◎	×	△
Corrosion fluidity resistance	◎	○	×
Thermal resistance	◎	◎	◎
Erosion resistance	◎	◎	○

Rating: ◎Excellent ○Good △Fair ×Poor
*Contact corrosion: The phenomenon in which a metal itself corrodes due to contact with extraneous matters

Table 2. Comparison of chemical resistance between various metals
(Source: Japan Titanium Society)

	Titanium	Stainless steel SUS 304	Stainless steel SUS 316	Copper
Sea water Room temperature	◎	◎*	◎*	○
Hydrochloric acid HCℓ 10%; Room temperature	○	×	×	×
Sulfuric acid H_2SO_4 10%; Room temperature	○	○	○	○
Nitric acid HNO_3 10%; Room temperature	◎	◎	◎	×
Caustic soda NaOH 50%; Room temperature	◎	◎	◎	◎
Sodium chloride NaCℓ 20%; Room temperature	◎	○	○	◎
Chlorine gas $C\ell_2$ 100%; Wet	◎	×	×	×
Hydrogen sulfide gas H_2S 100%; Wet	◎	○	◎	×
Sulfurous acid gas SO_2; 30–90C	◎	○	○	×

Rating: ◎<0.05 ○0.05~0.5 △0.55~1.27 ×>1.27 mm/year
*Pitting and crevice corrosion are likely to occur.

2. Great strength

Titanium is almost as strong as steel, and it is the strongest of all metals for its mass or the strongest in terms of specific gravity. For application as a building material, JIS Type 1 — which is highly workable — is mainly used.

Table 3. Specifications for pure titanium for industrial use (JIS products)

	Chemical composition						Mechanical properties (thickness: 0.5-15 mm, excl.)			Bend test (thickness: 0.5-5 mm, excl.)	
	H	O	N	Fe	C	Ti	Tensile strength (N/mm²)	Proof stress (N/mm²)	Elongation (%)	Bend angle	Inside radius
JIS Type 1	≦0.013	≦0.15	≦0.03	≦0.20	≦0.08	Remainder	270−410	≧165	≧27	180°	Thickness by 2
JIS Type 2	≦0.013	≦0.20	≦0.03	≦0.25	≦0.08	Remainder	340−510	≧215	≧23	180°	Thickness by 2
JIS Type 3	≦0.013	≦0.30	≦0.05	≦0.30	≦0.08	Remainder	480−620	≧345	≧18	180°	Thickness by 3

3. Light weight

The specific gravity of titanium is 4.51– 60% that of steel, half that of copper and 1.7 times that of aluminum. Being such a lightweight metal, titanium imposes less burden on a structure, and permits ease of fabrication.
According to use, it eliminates the need for corrosion-combating expenses, and enables further weight reduction.

4. Minimum thermal expansion

Titanium’s coefficient of thermal expansion is half that of stainless steel and copper and one third of aluminum. Having a thermal-expansion coefficient quite near those of glass and concrete, titanium can be used in combination with these materials.
Thus, with little susceptibility to expansion or contraction from temperature changes, titanium offers great ease and freedom in design and execution in long-term use.

5. Excellent aesthetic qualities

Titanium itself has an excellent texture and has a tastefully subdued silver color.
Titanium is also available in many varied colors developed by the anodic oxidation method.

6. Environmentally sound

Titanium is an innoxiously metal.
Only slight dissolution of metal ions makes titanium a very friendly metal to humans and the environment.

7. Others

Among the other major properties titanium offers are:
① Small Young’s modulus (elastic modulus).
② Small thermal conductivity.
③ A high melting point.
④ Non-magnetism.

Table 4. Comparison of physical properties between titanium and other metals

Item / Metallic materials	Titanium	Stainless steel SUS 304	Stainless steel SUS 316	Iron	Copper	Aluminum
Melting point °C	1,668	1,398~1,453	1,370~1,397	1,530	1,083	660
Specific gravity	4.51	7.93	8.0	7.9	8.9	2.7
Thermal expansion coefficient $\times 10^{-6}$/°C (20~100)	8.4	17.3	16.0	12.0	17.0	23.0
Thermal conductivity caℓ/cm²/sec/°C/cm	0.041	0.039	0.039	0.150	0.920	0.490
Electric resistance μΩ-cm	47	72	74	9.7	1.7	2.7
Young’s modulus Kg/mm²	10,850	19,300	19,300	21,000	11,000	7,050

Titanium is officially approved as a non-combustible material.
(Minister of Land, Infrastructure and Transport Certification No. “NM-8596”)

1. Basic characteristics of titanium building materials

8. Survey data on corrosion resistance

(1) Data on corrosion tests of metallic materials in spa areas

Corrosion of metallic materials at spa areas is a frequent cause of a variety of environmental problems and accordingly it is necessary to pay prudent attention in selecting metallic material for service in these areas. As a typical example of corrosion tests conducted at spa areas, the test results obtained at the Zao spa, an area noted for its high acidity, are introduced below.
(Source: *Titanium and Zirconium*, Vol. 35, No. 4 page 22, October 1987)

Table 5. Major constituents of the Zao springwater *(unit: mg/kg)*

	Temperature (°C)	pH	$C\ell^-$	SO_4^{2-}	Fe^{2+}+Fe^{3+}
Springhead	52.5	1.30	738.6	5,070	94.3
Public Bath	46.7	1.35	845.3	5,460	106.0

Due attention should be paid as corrosion conditions differ according to the composition of springwater.

Table 6. Degree of corrosion of various metallic materials obtained in the corrosion test at the Zao spa (Exposure period: 6 months) *(unit: mg/dm²/day)*

	Exposure at the springhead	Immersion at the springhead	Exposure at an interior wall of the bathhouse	Exposure at an exterior wall of the bathhouse	Immersion in the bath
Pure titanium	0	0	0	0	0
Stainless steel SUS 304	—	Melted*	1.99	—	Melted*
Ordinary steel product SS400	46.22	Melted*	41.55	19.33	Melted*
Tough-pitch coated steel	73.66	165.94	64.83	17.11	31.77
Pure zinc metal	0.66	Melted**	2.39	0.55	Melted**
Aluminum 5052	0	74.77	0	—	109.49
Nickel	0.66	341.44	3.83	1.83	58.49

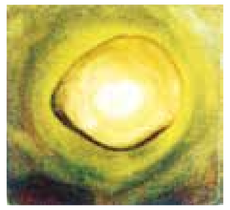
* Melted within two months
** Melted after immersion of 10 days, —: abnormal value

(2) Results of surveys on acid rain by NIPPON STEEL (Research into application of titanium for the protection of cultural assets)

Copper has been applied as the material for roofing of shrines and Buddhist temples because the copper surface develops deep verdigris. However, deterioration of the environment such as acid rains is causing diverse problems. The adverse effect of acid rain on copper application lies in that unstable basic copper sulfate is formed rather than stable basic copper carbonate (verdigris). This phenomenon poses not only aesthetic but also corrosion problems, in particular pitting corrosion (raindrop corrosion) caused by the dripping of acid raindrops. Further, the copper has a possibility of being corroded by decoction from mortar and fumigated tiles. Such corrosion and other problems affecting copper application have become a notable issue from the viewpoint of the protection of cultural assets and thus expectations are becoming high for titanium application. (Application examples: priests' living quarters at Ikkyuji Temple, tea-ceremony houses at Koetsuji Temple, Naritaya and Yakuoin Temples, others)

Photo 1 shows the results of simulated raindrop corrosion tests by dripping synthetic acid rain [H_2SO_4 : HNO_3 : $HC\ell$ =1.4:1.4 (mol ratio), pH=4.6].

Photo 1. Metallic surfaces after simulated raindrop corrosion tests by dripping synthetic acid rain

Ti (alumina blast finish)		Cu	
After 2 days 	After 66 days 	After 2 days 	After 66 days 

9. Workability

(1) Formability

There are no particular differences between titanium and ordinary and stainless steels. In the case of titanium JIS Type 1, it can be formed employing practically the same tools, jigs, etc., used for ordinary and stainless steels.

Due attention should be paid to the larger spring-back of titanium than ordinary and stainless steels.

(2) Weldability

Seam and spot welding can be applied to titanium under the same atmospheric conditions and manner as for stainless steel. When general welding methods (mainly TIG welding) are applied, stricter welding control than for stainless steel such as the necessity of argon gas shielding is required for titanium. There are no fears of weldment corrosion and stress-corrosion cracking.

NIPPON STEEL holds titanium welding training courses periodically to provide appropriate guidance on welding technology.

(3) Bonding and adhesion performances

Titanium's bonding with visco-elastic and sealing materials and adhesion to coating film are identical to those of stainless steel and aluminum.

10. Execution and applications

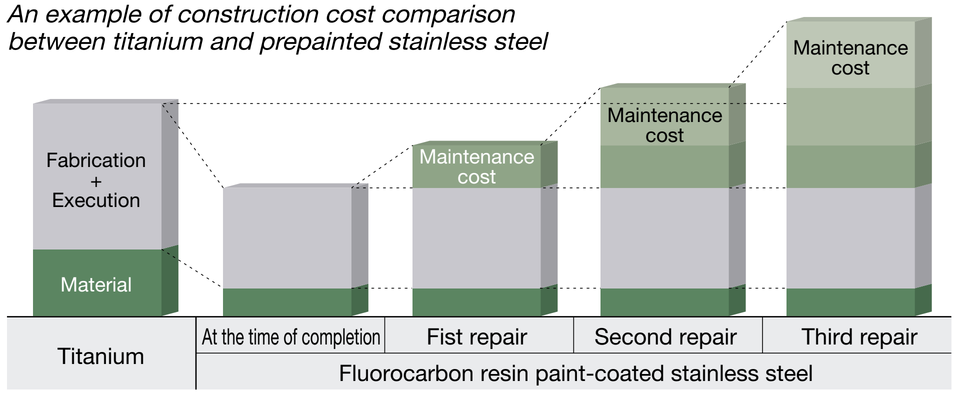
Most of the execution methods for exterior materials (roofing and walling) of conventional metals can likewise be applied to titanium.

11. Economics

Titanium, when used as a roofing and exterior material, may seem rather expensive in initial coat on a base-metal basis in comparison with other materials. But, the elimination of re-painting, re-roofing and other such needs brings running costs steeply down to an extremely low level. Over a long span of 20 to 30 or more years, titanium will come out a winner in terms of life-cycle cost.

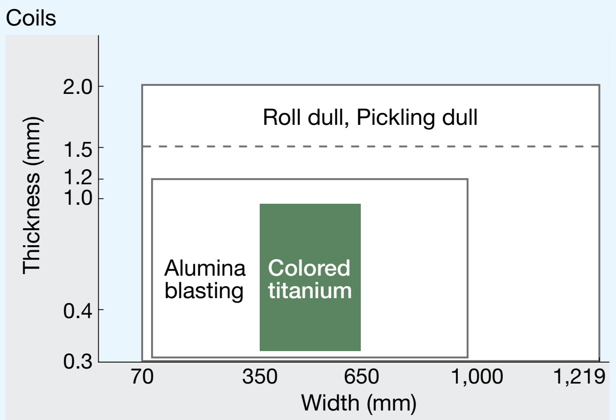
This advantage becomes even more marked in highly corrosive environments such as coastal, industrial and urban areas.

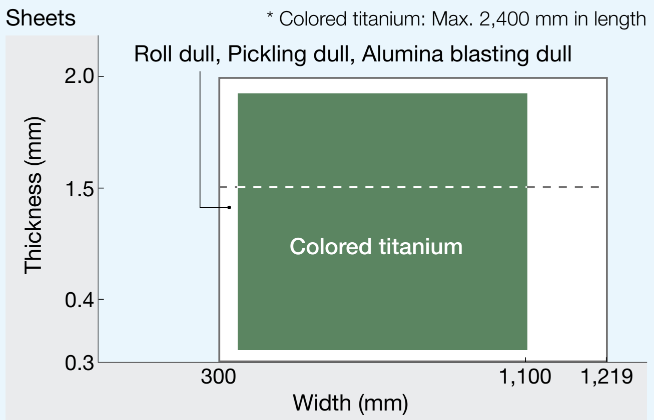
An example of construction cost comparison between titanium and prepainted stainless steel



[Conditions] **Construction method:** Welding method
Application conditions: Titanium — Basic texture
Stainless steel — Fluorocarbon resin paint-baked
Repairing cycle for stainless steel: 15 to 20 years before first repair, and thereafter repainting / repair every 5 to 10 years.

Range of availability of our products (Cold rolled sheets)





*Please feel free to contract us to discuss manufacturing to order outside of the values and specifications stated above.

2–1. An extensive product menu (Surface finish)

[Pat. No. 3688762, No. 3406726, No. 3397927, No. 3117876, No. 3453257, and No. 3655932]

NIPPON STEEL has an extensive menu of titanium materials consisting of various combinations of three kinds of surface finish and several tens of colors which are suitable for applications ranging from modern buildings to traditional Japanese buildings and also monuments.

Ⓐ Roll dull finish (ND10, ND20, SD3)

Ⓑ Alumina blasting finish (AD03, AD06, AD09)

→ + Coloring* (anodic oxidation)

*See Page 8.

Ⓒ Pickling dull finish* (VP20)

*Please contact us if you would like to request acid pickling with a dull finish.

Ⓐ Roll dull finish

After vacuum annealing (VAF), titanium materials are dull-finished on a skin-pass mill.

Roll dull, which is our main product, is used on a great many buildings.

Spherical observation deck at Fuji Television's headquarters
Surface: Roll dull (ND10)
Area: 2,800 m²
Weight: 14 tons
Completed: 1996

Hefei Lakeside International & Convention Center
Surface: Roll Dull (ND20)
Area: 13,000m²
Weight: 21 tons
Completed: 2011

Saemangeum Exhibition Center Surface – Roll Dull (ND20)
Surface: Roll Dull (ND20)
Area: 4,300m²
Weight: 10.4 tons
Completed: 2011

Ⓑ Alumina blasting finish

Alumina powder is blasted directly onto the titanium.

Alumina blasted titanium, which is aimed at creating the appearance of smoked tiles, is used on traditional Japanese buildings, particularly temples and shrines.

● 2003 Good Design Award
"Titanium temple roof/
Titanium project for protecting historical buildings"

● Fiscal 2005 Otani Art Museum Award
"A roof made of dream material that has traditional beauty
Alumina blasting finish titanium roofing and exterior materials"

Koetsuji Temple /Main hall
Surface: Alumina blasting (AD03)
Area: 700 m²
Weight: 1.2 tons
Completed: 1997

Daichuji Temple
Surface: Alumina blasting (AD03)
Area: 660 m²
Weight: 1.2 tons
Completed: 2006

Showa Hall
Surface: Alumina blasting (AD09)
Area: 4,200 m²
Weight: 56 tons
Completed: 1998

Ⓒ Pickling dull finish

A dull-finish is given by pickling and skin passing.

When titanium is pickled, it appears whitish. This is a representative example which shows that color-tone from one lot to another over a large area can be reduced.

Shimane Art Museum
Surface: Pickling dull (VP20)
Area: 10,000 m²
Weight: 60 tons
Completed: 1998

2–2. An extensive product menu (Surface finish)

Ⓐ Roll dull + color finish

Uchinada Town Office
Surface: Roll dull (ND20), green coloring
Area: 1,700 m²
Weight: 6 tons
Completed: 1998

Ⓑ Alumina blasting + color finish

Kitano Tenmangu/Treasury
Surface: Alumina blasting (AD09), verdigris coloring
Area: 1,000 m²
Weight: 4 tons
Completed: 1998

Nara National Museum (No. 2 Annex)
Surface: Alumina blasting (AD03), brown coloring
Area: 6,000 m²
Weight: 12 tons
Completed: 1998

Ashitaka Shrine
Surface: Alumina blasting (AD09), verdigris coloring
Area: 440 m²
Weight: 0.4 tons
Completed: 2006

Ryukotokuji Temple
Surface: Alumina Blasting (AD09), Verdigris coloring
Area: 2,500m²
Weight: 5.9 tons
Completed: 2009

Colored titanium

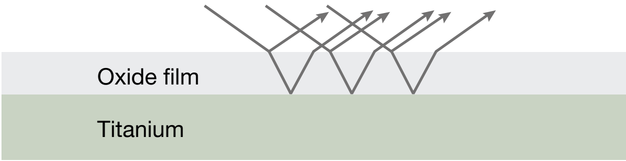
Coloring of titanium

We have constructed a quality control setup that enables us to stably provide colored titanium construction material.
① Uniform color
② Technology for ensuring adhesion of the film
③ Development of new products
④ Development of color forming protective film, and so on

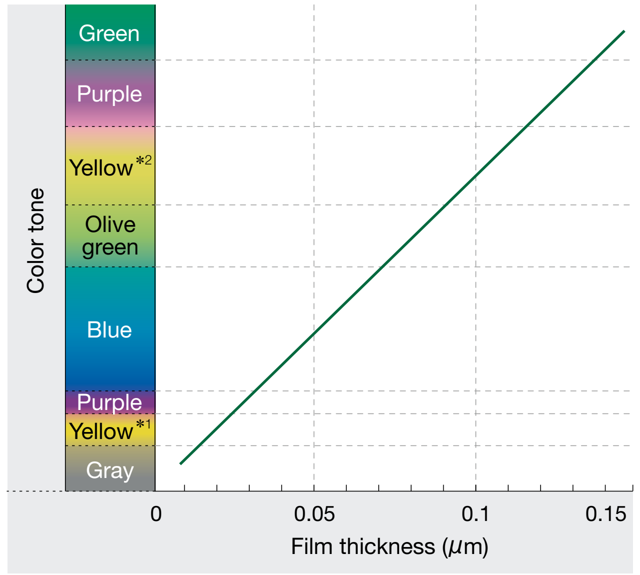
Principle of coloring of titanium

Coloring (Anodic oxidation)
When a thin oxide film (colorless and transparent) is formed on the titanium surface by means of the anodic oxidation method, color can be seen as a result of interference of light. A wide range of colors can be produced by changing the film thickness.

Principle of interference color



Relationship between film thickness and interference color (Theoretically calculated values)



When using colored titanium, please understand the following points.

①**The oxide film on the surface of titanium is extremely thin, so the color tone is strongly influenced by the surface conditions of the base metal.**

Titanium sheets that have different surface finishes may appear different in color, even if the titanium oxide film formed on them is the same thickness. Also, even if sheets have the same surface finish, the color will differ slightly from one coil to the other.

For this reason, in addition to checking the color using color samples, we check the color of the actual ordered material by coloring a part of the material prior to the actual coloring process. When you intend to use two or more coils, we recommend that you control the coils jointly with the fabricator so as to minimize color differences.

②**Because titanium is colored by light interference, the color may sometimes appear different depending upon the season, weather, time of day, and viewing angle.**

When it rains, for example, the same color can look completely different. This is a feature of interference colors, and you may find that such a color change is a pleasing aspect of colored titanium.

③**The oxide film may grow depending upon the weather atmospheric conditions, causing the color to change.**

With our titanium products, there have been cases in which the oxide film grew, causing the color to change from yellow (*1) whose film thickness is thin, to purple over a period of about 10 years. The main factors contributing to this phenomenon are the extreme thinness and the narrow range of the oxide film required to produce the initial yellow color.

For a customer who wants yellow, we recommend yellow (*2) because the oxide film needed to develop the color is relatively thicker and the oxide film range of that color is comparatively less narrow. Customers should note, however, that the color of any colored titanium may change gradually with time depending upon the environmental conditions.

*The hue changes in the sequence gray, yellow, purple, blue, olive green, yellow, purple, and green, as the thickness of the oxide film increases.

④**Titanium becomes dirty like other metals. Finger marks get on it. Depending upon the type of contamination**, the titanium surface may appear discolored, but the contamination can be removed with detergent. Note, however, that if the contamination is allowed to remain, it may become difficult to remove.

We recommend that you use a neutral detergent or our recommended detergent to clean titanium. If you use a detergent that contains a strong acid, the oxide film on the surface may dissolve, preventing the original color from being restored. (See Page 15.)

3–1. Development of titanium that does not readily become discolored

[Fiscal 2004 Japan Institute of Metals Technical Development Award; Pat. No. 3566930, and No. 3406898]

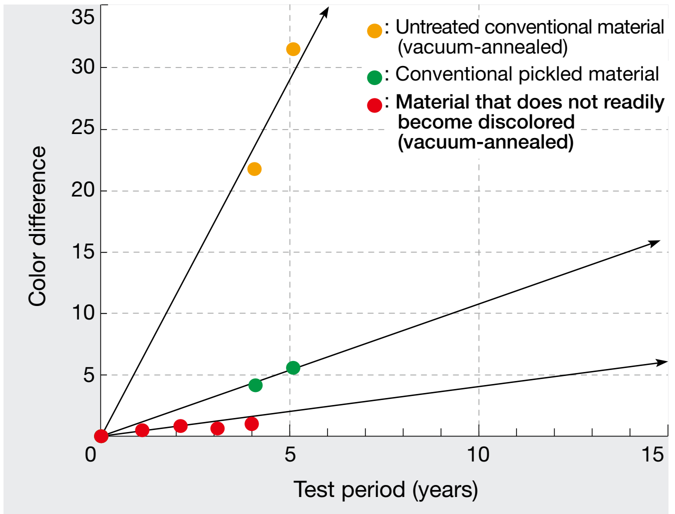
We developed titanium for building use that does not readily become discolored, and at present we use it for all building material products (surface finishes) including colored materials.
As a result of exposing titanium for four years in Okinawa, only a very small amount of discoloration occurred in titanium for building use that does not readily become discolored.

Exposure test for titanium building material that does not readily become discolored

- **The pH value of acid rain in Okinawa is roughly the mean value (pH 4.8, in 2003), but because of the high temperature and humidity this is one of the regions in the Japan where discoloration occurs most rapidly.**
- The mean pH value of acid rain throughout Japan is pH 4.7, (2003 data). Note: pH 5.6 or less is acid rain; Neutral is 7.0.

Okinawa exposure test

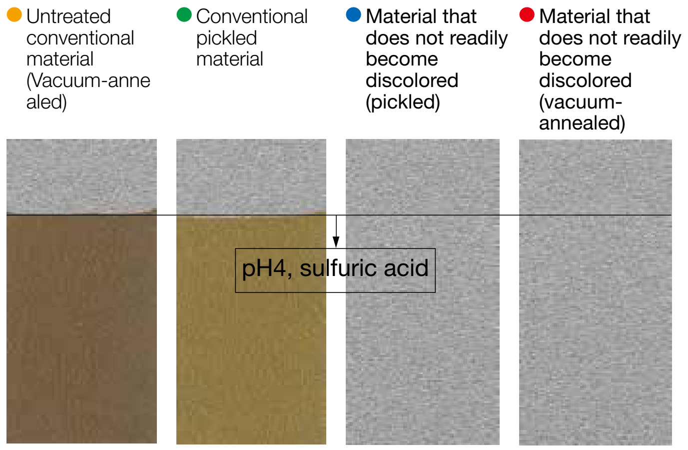
Results of 4-year exposure test in Okinawa



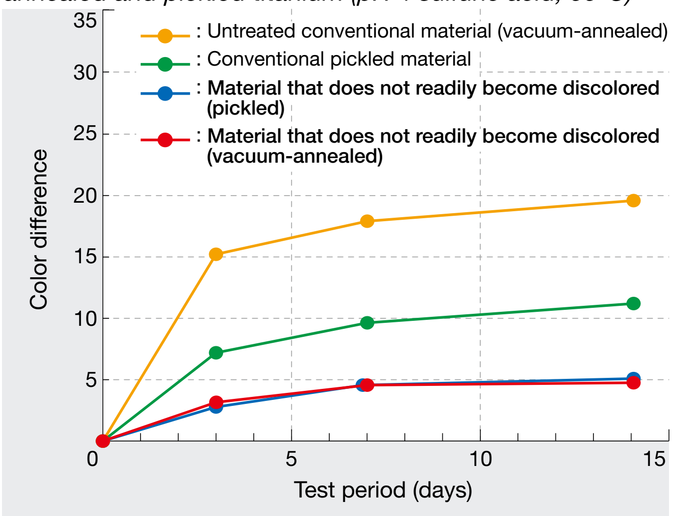
We established an accelerated test method that reproduced the discoloration.
As a result of this test, it was found that titanium for building use that does not readily become discolored undergoes relatively little discoloration compared to untreated material.

Accelerated test of titanium building material that does not readily become discolored

Results of accelerated test
(The top 1/5th is the color prior to the accelerated test.)



Results of discoloration accelerated test of vacuum-annealed and pickled titanium (pH 4 sulfuric acid, 60°C)

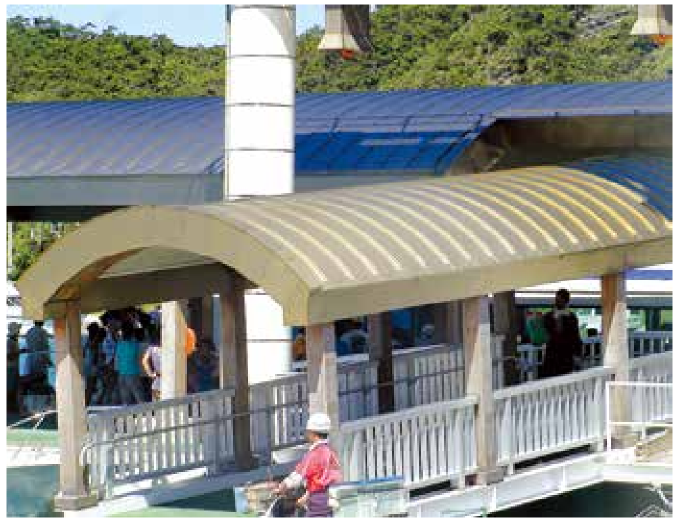


When titanium for building use that does not readily become discolored is colored, the discoloration resistance improves remarkably.

Application to coloring of titanium for building use that does not readily become discolored

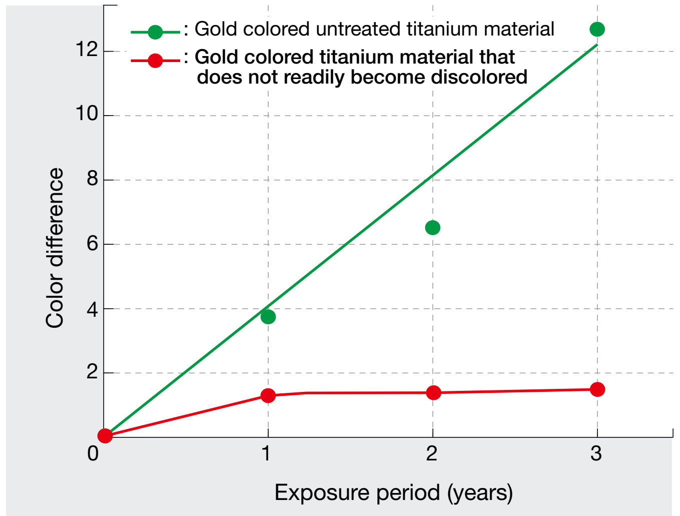
- **The graph below shows the results of exposure of titanium of the color corresponding to a thin film at which the discoloration occurs most easily (gold or yellow), in Okinawa. Even after three years' exposure, the change in color difference of the material, which does not readily become discolored, is very small.**
- **The Zamami Pier (made of material that does not readily become discolored) retains its gold color two and a half years after it was constructed in Okinawa.**

Zamami Pier, Okinawa Prefecture



Completed 2002 (Photographed 2004) [Thin film gold color is maintained (Material which does not readily become discolored)]

Change in color difference of gold colored titanium in Okinawa in the case where conventional material and also material that does not readily become discolored are used as base materials



Note: In the above color difference range, the color difference and oxide film thickness are proportional to each other, so the growth of the oxide film on the treated material is not linear.

Points to note concerning titanium building material that does not readily become discolored

- **This technology reduces the rate of growth of the oxide film in a natural environment, and thus slows down the speed of discoloration. It does not stop discoloration from occurring.**
- Material that does not readily become discolored which was installed during or after 2000 and also material that has been subjected to an exposure test have presently undergone little change in the base metal or the color, and maintains a satisfactory condition.
- **It is considered that there is a possibility of discoloration occurring in tropical regions of high temperature and humidity or regions where severe acid rain falls.**
- Like other metals, titanium sometimes appears discolored due to dirt or finger marks. Contamination can be removed by carrying out appropriate cleaning. If the contamination is allowed to remain, it will become difficult to remove.

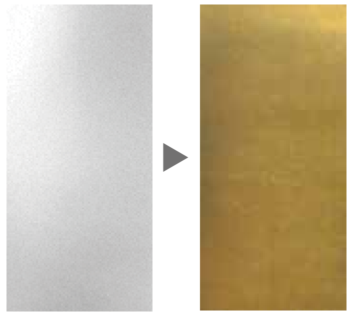
3–2. Development of titanium that does not readily become discolored

Discoloration phenomenon

At the beginning of the 1990s, some of the titanium roofs that had been installed prior to that time changed color from silver to brown.

The surface of titanium has a chemically stable oxide film (passive film). The protective action of this film provides excellent resistance to corrosion. If the oxide film on the surface of the titanium (thickness approx. 0.01 μm) grows to between 0.03 and 0.05 μm, the original silver surface will appear brown as a result of interference light. This phenomenon is called discoloration of titanium. (It does not adversely affect the corrosion resistance.)

Examples of discoloration
[The test piece is conventional vacuum-annealed material (VA).]

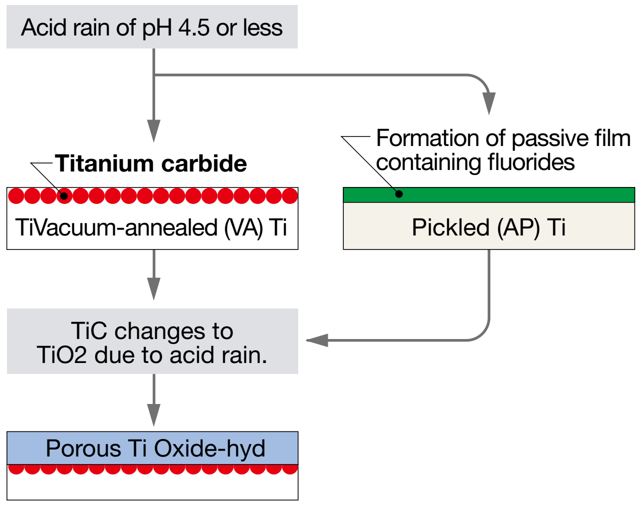


Before exposure to atmosphere | After 7 years' exposure in Oita City

Mechanism of discoloration

As a result of investigating the discolored areas, a minute amount of carbide and fluorides was found remaining in the oxide film and on the surface of the titanium base metal. Various tests were carried out, and as a result it was found that these substances react with acid rain, causing the film to grow. The higher the atmospheric temperature, the more pronounced is this trend.

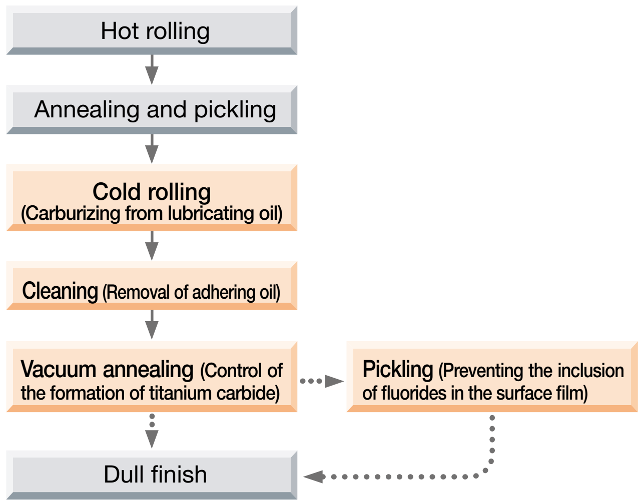
Mechanism of discoloration of titanium (pattern diagram)



Development of titanium building materials that does not readily become discolored

It is known that carbon, the cause of discoloration, which is included in rolling mill lubricant used for cold rolling during the manufacture of titanium, remains on the surface of titanium, and also fluorides, which are included in the acid solution used for pickling subsequent to cold rolling, remain on the surface of titanium. Accordingly, we established manufacturing technology to remove most of the carbon and fluorides from the surface of the titanium.

Method of manufacturing titanium cold-rolled sheets
(Points concerning the improvement of resistance to discoloration)



In order to evaluate the performance with respect to the discoloration of the manufactured titanium, an exposure test was carried out in Okinawa and also a discoloration accelerated test method based on the mechanism of discoloration was developed. As a result, the effectiveness of this method of manufacturing titanium was verified. (See Page 10.)

4. Reduction of color-tone from one lot to another

We have provided materials for a number of major properties. In the process, we have amassed the know-how in control technologies to make products in a sufficient quantity to extensively cover a large area, with the least possible variations in color tones between lots (coils).
In addition, we are also able to provide roofing and exterior-execution companies with information required for lot control*.

*Lot control
Base metal (uncoated) for use as a building material may often come in delicately varied color tones. Titanium is no exception. In order to prevent impairment of the class of the whole building by such an element, it is a common practice to use coils (panels) in the order of approximation and gradation in color to make color variations inconspicuous.

The photographs below are representative examples of reduction of color variations.

Kyushu National Museum (17,000 m^2)

Kyushu Oil Dome (32,000 m^2)

Hangzhou Grand Theatre (10,000 m^2)

Hozomon of Sensoji Temple (1,080 m^2)

In this case, the degree of luster of the titanium has been deliberately varied by using two kinds of alumina blasting to give the impression of tiles.

5. A wealth of application technology

[Pat. No. 3369352, No. 3362326, No. 3358699, and No. 3505036]

Distortion of the material after rolling is small, and the design performance as a roof is maintained.

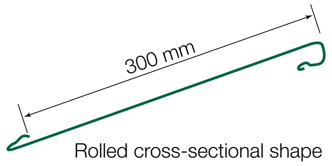
Development of a material that has little distortion during forming

● Sometimes during rolling, pocket waves occur on titanium. We have developed technology to reduce this phenomenon.
● We have succeeded in significantly reducing pocket waves by carrying out the following subsequent to vacuum annealing.
① Performing skin pass rolling by using dull rolling.
② Applying waves in advance to the edges of the titanium sheet

Shape after rolling (stepped roofing)

No edge waves ⇨ Rolling

Application of edge waves ⇨ Rolling



Rolled cross-sectional shape

Kyushu National Museum
(Constructed by Sanko Metal Industrial Co., Ltd.)

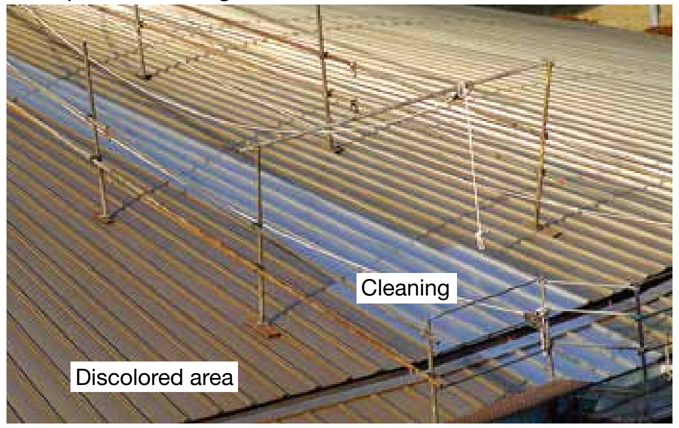
Application of edge waves ⇨ Rolling (with ribs) ⇨ Seam welding

Shape after installation
(welding method)

Development of a suitable cleaning agent

Regarding cleaning, we recommend that you use a commercially available detergent according to the manual. We have independently developed three kinds of cleaning agent, and can introduce the manufacturer. We also have available strong cleaning agents (Type [B] and Type [C]) for removing discoloration. Note, however, that if you use these strong cleaning agents, the surface film will be removed as far as the base metal.

Example of cleaning



Developed cleaning agents

	Cause of discoloration	Base metal	Colored titanium
Type (A)	Steel rust, dirt, etc.	○	○
Type (B)	Slight discoloration (growth of the oxide film)	○	×
Type (C)	Discoloration (growth of the oxide film)	○	×

※If there are places in the roof and other areas where rainwater is liable to form pools, titanium becomes contaminated like any other metal. Contamination, if left unattended, may sometimes become hard to remove. Contamination due to drips of calking material also becomes hard to remove with time. It is recommended that all these points be taken into consideration in the early design stages.

Cleaning method

① **Removing adhesive remaining on the protective film**
Wipe off adhesive using a sponge or cloth moistened with alcohol, benzene, or thinners, or a mixed solution consisting of alcohol and toluene or benzene (in sequence from the weakest acting liquid). It is important to wipe the surface of the titanium with an unused, clean cloth before these solvents have dried.

② **Removing contamination due to finger marks or dirt from the hands**
In almost all cases, you can remove contamination using a neutral detergent or soapy water. If you are unable to do so, use an organic solvent (alcohol, benzene, etc.). In this case, you must observe the abovementioned precautions.

③ **Removing contamination due to roofing material and concrete**
Wipe away contamination using a sponge or cloth moistened with a 5% solution of hydrochloric acid in water.

④ **Removing contamination due to zinc from scaffolding material**
Wipe away contamination using a sponge or cloth moistened with a 15% solution of nitric acid in water.

⑤ **Removing contamination due to rainwater or dust**
In almost all cases, you can wipe away contamination using a sponge or cloth moistened with a neutral detergent or an alkaline detergent. If you are unable to do so, you may be able to remove the contamination by applying a cleaner containing an abrasive to a soft cloth, and then rubbing gently and uniformly.

The above is a description of the various cleaning methods. In all cases, thoroughly wash the surface with water after cleaning, and ensure that no traces of cleaning agent remain.

⑥ **Removing contamination from colored titanium**
Of the abovementioned cleaning methods, do not remove contamination using hydrochloric acid, nitric acid, or a cleanser, because the film that produces the color will be affected, preventing the surface from being restored to its original condition.

Precautions for cleaning

① There are various causes of contamination and discoloration of titanium building material, so it is necessary to use a cleaning method that matches the particular circumstances. Do not abruptly start cleaning the entire surface. First carry out test cleaning on a small area, and check the removal of the contamination or discoloration. If the result of the test is satisfactory, use that method to clean the entire surface.

② When using a cleaning implement such as a cloth, sponge, loofah, scrubbing brush, cleaning brush, fine nylon pad, and so on, be sure to move it in the direction parallel to the polishing marks on the titanium. Also, move your hand in such a way as to apply a uniform force as far as possible. If you move the cleaning implement in circles, the contamination will be difficult to remove, and also the luster lines will be erased and color irregularity will occur, marring the appearance of the titanium surface.

③ Even in the case of fairy stubborn contamination, avoid using a coarse polishing agent, sandpaper, steel wool, or the like. Not only will this erase the luster lines on the titanium, but also the surface will become scratched, which may cause it to become contaminated.

④ When using a commercially available cleaning reagent to remove contamination from the surface of titanium, clean not only the contaminated part but also the vicinity as well. If you clean the titanium surface only partially, irregular color will occur, marring the appearance of the titanium.

⑤ When cleaning building tiles, marble, aluminum, and so on, if the cleaning reagent that you used splashes on the surface of the titanium, be sure to wipe away the reagent with a damp cloth. If you leave the reagent on the titanium, discoloration may occur.

⑥ In the case of colored titanium, consult with the manufacturer prior to use.

(Source: Japan Titanium Society)

Examples of use of titanium for building applications

Roll dull (ND20) was used in the T.C.M. (Titanium Composite Material) of Mitsubishi Chemical.

National Grand Theater (China)
Surface: Roll dull (ND20)
Area: 43,000 m²
Weight: 65 tons
Completed: 2007

©Tsuyoshi Onishi

Hangzhou Grand Theatre (China)
Surface: Roll dull (ND20)
Area: 10,000 m²
Weight: 15 tons
Completed: 2003

The Taipei Arena is the first instance of full-fledged use of titanium in Taiwan.

Taipei Arena (Taiwan)
Surface: Roll dull (ND20)
Area: 20,000 m²
Weight: 50 tons
Completed: 2005

We offer particularly lustrous colored products for Frank O. Gehry's projects

Hotel Marques de Riscal (Spain)
Surface: Roll dull (SD3)
Area: 2,400 m²
Weight: 12 tons
Completed: 2004

Examples of use of titanium for building applications

The Kyushu Oil Dome is the first example of the use of titanium that does not readily become discolored. Roll dull (ND20) was used.

Kyushu Oil Dome
Surface: Roll dull (ND20)
Area: 32,000 m^2
Weight: 80 tons
Completed: 2001

JR Hakodate Station is the first structure where titanium building materials were adopted for exterior panels on a full scale, as a result of their feature of being resistant to changes in color.

JR Hakodate Station
Surface: Roll dull (ND20)
Area: 1,000 m^2
Weight: 7 tons
Completed: 2003

The teahouse of the Kinkakuji Temple, which is a World Heritage site, uses alumina blasting.

Teahouse (Josokutei) of Kinkakuji Temple
Surface: Alumina blasting (AD03)
Area: 100 m^2
Weight: 0.5 tons
Completed: 2003

The roof of the Hozomon of Sensoji Temple was the first instance of using titanium Japanese tiles. Also, our highly workable material, Super-Pure Flex, has been used for the ridge-end tiles.

Hozomon of Sensoji Temple
Surface: Alumina blasting (AD03, AD06)
Area: 1,000 m^2
Weight: 8 tons
Completed: 2007

●Awarded the Fiscal 2006 Otani Art Museum Award
"Titanium stepped Japanese tile roof and ridge-end tiles"

Examples of use of titanium for building applications

Titanium roofing with an alumina blasting finish adopted for the teahouse of the Raku Kichizaemon-Kan, newly opened on the premises of the "Sagawa Art Museum" in Moriyama City, Shiga Prefecture.

Teahouse (Raku Kichizaemon-Kan) of Sagawa Art Museum

Surface: Alumina blasting (AD03)
Area: 400 m^2
Weight: 1 tons
Completed: 2007

Gold titanium used in the construction of the roof of the Miyajidake Shrine.

Miyajidake Shrine

Surface: Roll Dull (ND20), Gold coloring
Area: 220m^2
Weight: 0.86tons
Completed: 2010

Reference materials

Table 1. Orders of stabilization of metals

	Orders of thermodynamic stabilization	Orders of practical stabilization in solution	
1	Gold	Rhodium	1
2	Iridium	Niobium	2
3	Platinum	Tantalum	3
4	Rhodium	Gold	4
5	Palladium	Iridium	5
6	Mercury	Platinum	6
7	Silver	Titanium	7
8	Copper	Palladium	8
9	Bismuth	Mercury	9
10	Arsenic	Gallium	10
11	Carbon	Zirconium	11
12	Lead	Silver	12
13	Nickel	Tin	13
14	Cobalt	Copper	14
15	Cadmium	Beryllium	15
16	Iron	Aluminum	16
17	Tin	Chromium	17
18	Molybdenum	Bismuth	18
19	Tungsten	Tungsten	19
20	Gallium	Iron	20
21	Zinc	Nickel	21
22	Niobium	Cobalt	22
23	Tantalum	Arsenic	23
24	Chromium	Carbon	24
25	Vanadium	Lead	25
26	Manganese	Cadmium	26
27	Zirconium	Zinc	27
28	Aluminum	Molybdenum	28
29	Titanium	Vanadium	29
30	Beryllium	Magnesium	30
31	Magnesium	Manganese	31

Table 2. Clarke number (Note)

Order	Element		Existing ratio (%)	Accumulated total
1	Oxygen	O	49.50	49.5
2	Silicon	Si	25.80	75.3
3	Aluminum	Al	7.56	82.9
4	Iron	Fe	4.70	87.6
5	Calcium	Ca	3.39	91.0
6	Sodium	Na	2.63	93.6
7	Potassium	K	2.40	96.0
8	Magnesium	Mg	1.93	97.9
9	Hydrogen	H	0.87	98.8
10	Titanium	Ti	0.46	99.2
11	Chlorine	Cl	0.19	99.4
12	Manganese	Mn	0.09	99.5
13	Phosphorus	P	0.08	99.6
14	Carbon	C	0.08	99.7
15	Sulfur	S	0.06	99.7
16	Nitrogen	N	0.03	99.8
17	Fluorine	F	0.03	99.8
18	Rubidium	Rb	0.03	99.8
19	Barium	Ba	0.02	99.9
20	Zirconium	Zr	0.02	
21	Chromium	Cr	0.02	
22	Strontium	Sr	0.02	
23	Vanadium	V	0.015	
24	Nickel	Ni	0.010	
25	Copper	Cu	0.010	
26	Tungsten	W	0.006	
27	Lithium	Li	0.006	
28	Cerium	Ce	0.005	
29	Cobalt	Co	0.004	
30	Tin	Sn	0.004	

(Note)
Clarke Number: The ratio of elements found in the upper layer of the earth's crust. Named after the American geochemist F.W. Clarke (source: The Chemistry Encyclopedia *Kagaku Daijiten*)
Titanium is the 10th most common element found in the upper layers of the earth's crust, and in terms of metals that are of practical use, it comes fourth after aluminum, iron and magnesium.

Table 3. Corrosion potential in seawater (Flow)