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"NON-AEROSPACE APPLCATION OF TITANIUM IN JAPAN"

Introduction

Industrial applications of titanium materials have been expanding widely in many areas.

Applications of titanium can be classified into two fields, namely aerospace and non-aerospace. From the outset titanium has been mainly used for aerospace applications in the United States.

In Europe both applications, aerospace and non-aerospace, have grown almost simultaneously. The situations in other countries may be similar to that of Europe.

Conversely in Japan, titanium has been used entirely for non-aerospace applications. Recently, however, Japanese aerospace applications are increasing gradually in accordance with the growth of the aerospace industry. We can expect non-aerospace applications, which are extremely varied, to increase greatly in the future. Titanium is still an expensive metal, but the growth of its overall consumption will entail a reduction of production costs which in turn will naturally brine about a further expansion in consumption.

TITANIUM - Toward The 3rd Metal

Anticipates to its salient features or high resistance to corrosion and heat, light weight and high strength, titanium is being used more and more in the fields of chemical industry, thermal and nuclear power generation, seawater desalination, building or deep-sea survey submarines, and aerospace. Thus finding expanding applications in aerospace, on land and in the ocean, titanium is attracting much attention as a new basic metal for coming generations.

In this paper, the recent status or typical resulting and newly growing applications in Japan will be described. In addition, the problems that need to be solved to allow further expansion of non-aerospace applications will be discussed.

The trends in consumption of titanium mill products in the USA, Europe and Japan are shown in Fig.1.[1)]

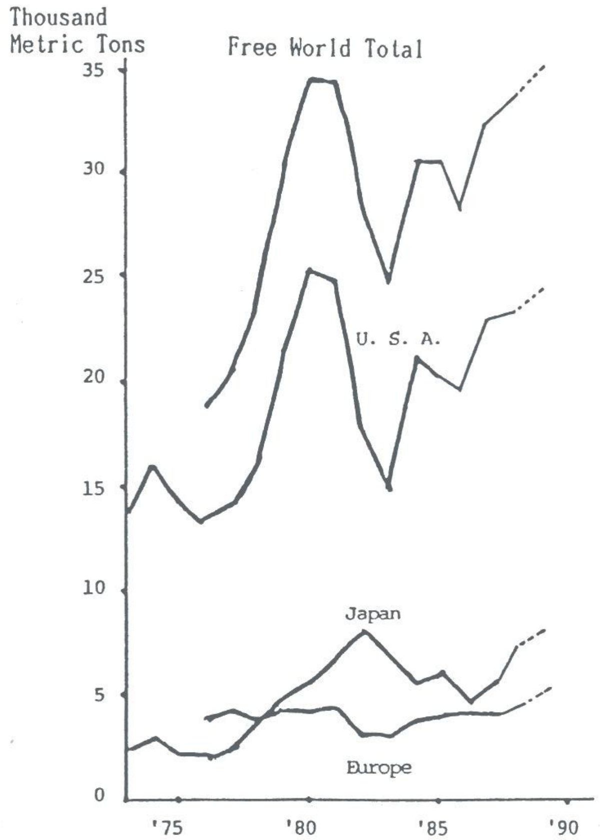


Fig.1 Shipments of titanium mill products in the free world.

Practical Applications

1. Power Plants of Electricities

(1) All-titan-condenser

Nuclear power plants, PWR- and BWR- types: are of large capacity, term shutdown for protection against radioactive pollution, is an important member of a nuclear power plant and tremendous effort has been made to prevent condenser trouble. The fully titanium tubed condenser was developed with this background, coming into increasing use as the zero-leakage condenser at nuclear power plants around the world as in Japan.

Concerning the strip for seam-welded titanium tubes, development of production technology of large-width, large-sized titanium strip by the use of conventional hot and cold rolling mills has contributed greatly to mass production and cost reduction through high productivity and yield.

Photos 1 and 2 show the reverse cold rolling and annealing/chemical pickling lines, respectively, in the cold-rolling process, after the strip is rolled by a seven-high hot tandem rolling mill.

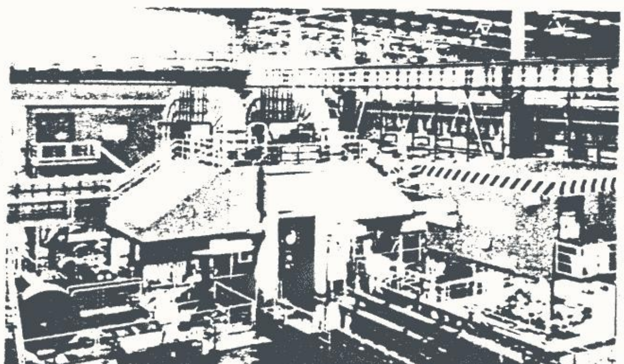


Photo 1 - Reverse cold rolling mill

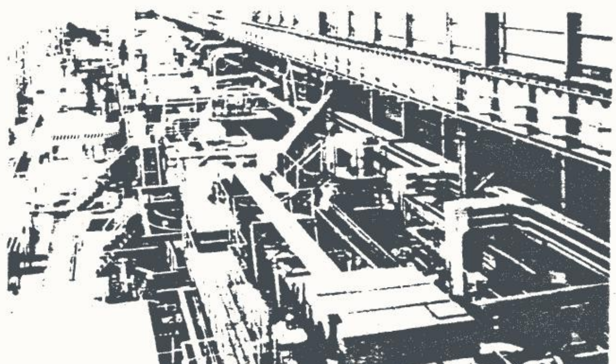


Photo 2 - Annealing and pickling line

To produce welded tubes, it is a common practice to use a tube-forming machine consisting of various tube-forming rolls, as shown in Fig.2, and a non-filler TIG welding machine. Advantages of this production method include high productivity realized by increased tube-forming speed. and excellent welded bead shape and as-welded quality. Applying the high-frequency pulsed arc to the conventional direct-current TIG welding power supply increases arc pressure, maintaining high penetration capacity and stiffness of the arc even in high-speed tube forming, and achieving a smoother bead surface, as may be observed in Fig.3.

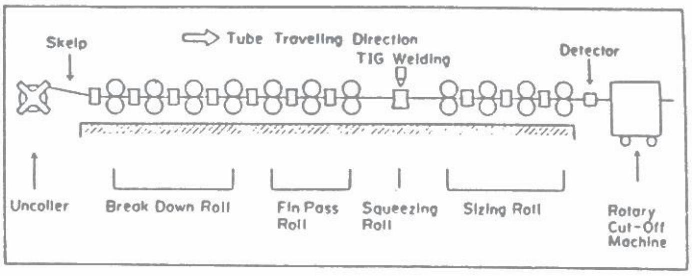
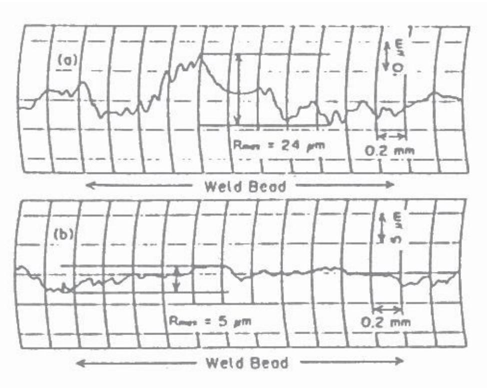


Fig.2 Schematic diagram of tube making equipment



Power source : (a) Conventional DC
(b) High frequency pulsed
Tube size : 25.4 Ø x 0.5 tmm
Welding speed : 5 m/min

Fig.3 Surface roughness measurement for titanium tube weld

Titanium tubesheet stock is precisely machined by a multiple-spindle drilling machine with the NC tape prepared by an automatic design program. Titanium has high resistance to deformation and low thermal conductivity. Therefore, molybdenum-cobalt-based high speed steel is used for cutting drills, and cutting speed is kept of one half that for naval brass tubesheets.

Titanium-clad steel plates (JIS G 3603) are also used for tubesheets for

titanium-tubed condensers. In titanium-tubed condensers the tube ends are not machined to have a bell mouth and the tube-hole wall is not grooved.
All-titan-condensers in service stand of 12 units, the total turbine output 12,602 MWe, in domestic nuclear plants as of June 1989, and the units employed titan condenser under construction stand at 13 stations with a total output of 10,407 MWe.
All the units are operating satisfactorily and, all-titan-condensers are enjoying more general acceptance and a growing reputation.[2)]
Recently, Kakogawa Works No.6 steam turbine of Kobe Steel employed a totally titanium-tubed condenser using more thinner wall 0.4mm thick tubes and titanium-claded steel tubesheet. For ancillary equipments, filters on the seawater inlet side, automatic tube reverse-washing system, and automatic condenser-tube cleaning device using sponge-rubber are introduced. In years to come, the operation performance of the condenser will be reported.[3)]

(2) Development of titanium-alloy long blading
Since 1974 Kobe Steel has been carrying out operating tests of 23" long Ti-6Al-4V alloy blades installed in its own 50 MW steam turbine power station at Kakogawa Steel Plant. As shown in Photo. 3, two groups of each five titanium alloy blades are fixed symmetrically keeping the weight balanced.
Beta titanium alloy is overlaid on the leading blades of the titanium alloy blade group for erosion shielding.
The titanium alloy blade with Beta-titanium alloy overlay shows much less erosion compared to 12% Cr Steel blade brazed with Stellite.
This results confirms the effect of Beta-titanium alloy overlay.[4)]

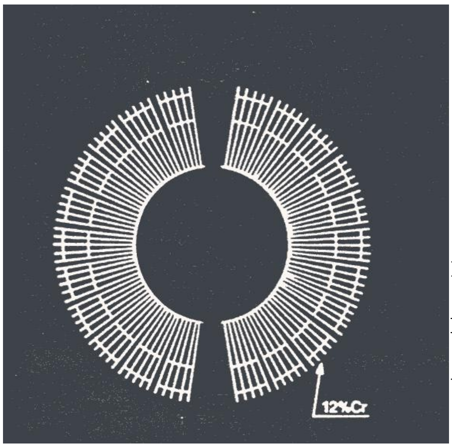


Photo 3
Location of 23" long
titanium alloy blades.[4)]

At present The Chubu Electric Power pioneerly worked cooperatively with three domestic turbine manufacturers (Toshiba, Hitachi, and Mitsubishi Heavy Ind.) and developed the world-longest 40-inch titanium alloy blade to be mounted on the 3,600 rpm turbines. Table 1 compares the physical properties of "Ti-6Al-4V" alloy with those of conventional high-chromium steel.

Because titanium has insufficient forgeability and anxiously embrittles by absorbing hydrogen or oxygen according to environmental conditions, actual blades were trial-made, and tested to ascertain effects of manufacturing method and process on material properties. The tests proved the "Ti-6Al-4V" can be satisfactorily used for blade material. Photo. 4 shows an example of blades made on trial.

Table 1 Comparison of Physical Properties of Ti-6Al-4V and High-Cr Steel[5)]

Items	Ti-6Al-4V	High-Cr Steel
Young's modulus	11,550 kgf/mm^2	22,100 kgf/mm^2
Poisson's ratio	0.32	0.26
Specific gravity	4.42	7.70
Tensile strength	≧91.4 kgf/mm^2	≧ 113 kgf/mm^2
Yield strength(0.2%)	≧84.4 kgf/mm^2	≧ 78 kgf/mm^2
Elongation	≧10%	≧13%
Reduction of Area	≧25%	≧30%

In the supersonic area, blades-cascade loss increases due to shock wave. To accommodate such loss, blade performance was investigated and the basic specifications were determined as shown in Table 2.

Table 2 Basic Specification of L.P. Last Stage Blades[5)]

Items	Long titanium alloy-blades	700 MW's conventionals
Length	40" (1,016 mm)	33.5"
P C D	104" ~ 107.2"	90.5"
Annular area	approx. 8.5 m^2	6.1 m^2
Circumf'l speed at blade-tip.	approx. 700m／sec.	approx. 600m／sec.
Numbers	68 ~ 90 pcs.	94 pcs.
Type of root	Contrary-Christmas tree or Fork type	Fork type
Material	Ti-6Al-4V	12Cr steel
Weight	16 ~ 23 kg／pcs.	16.7 kg／pcs.

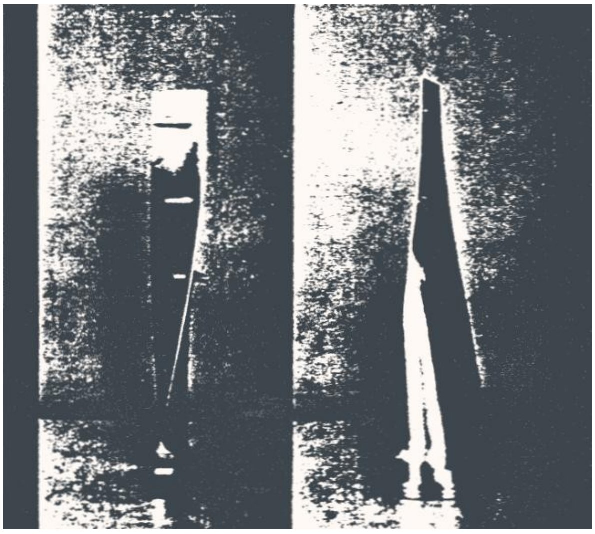


Photo 4 3,600 rpm 40-inch Ti-6Al-4V blade[4)]

Fig. 4 shows that better thermal efficiency of 1.5% or a saving of several million US$ annually by using 40" long titanium alloy blades, which are now under development, will be achieved, compared to the conventional Hi-Cr Steel blades, when actually applied to a 700 MW commercial steam turbine.

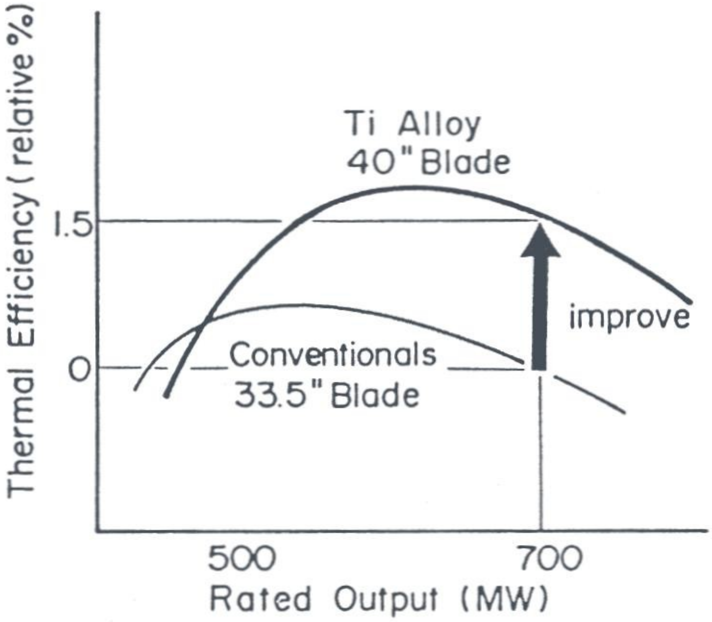


Fig. 4
Improvement of thermal efficiency applying of 40" long titanium alloy blade. [5)]
Courtesy of Chubu Electric Power Co.

At present concrete investigation has been made on the application of long blades to the steam turbines No. 1 to 3 of The Hekinan Thermal Power Plant of The Chubu Electric Power now just under construction.[5)]

(3) Spent nuclear fuel reprocessing

In the spent nuclear fuel reprocessing by Purex process using nitric acid (HNO_3), stainless steels have been used for the process equipment although some leakage, caused by the corrosion of the material, has been experienced.

Therefore, it is expected that new type materials which have better corrosion resistance against HNO_3 solutions are developed.

As is known well, Zirconium (Zr) , Titanium-5% Tantalum alloy (Ti-5Ta) and Titanium (Ti) have an excellent corrosion resistance against HNO_3 solutions and so they seem to be appropriate materials for the Purex process equipment.

However, their corrosion resistance in the Purex process environment has not yet been clearly demonstrated.

Thus, the corrosion behaviors of Zr, Ti-5Ta and Ti were studied in simulated reprocessing environments (non-radioactive) , that is in HNO_3 solutions with and without the fission product elements Ru, Rh and Pd ions.

As shown in Fig. 5, Ti-5Ta alloy shows superior corrosion resistance in a concentrated boiling nitric acid solution compared to normal CP grade. The main feature of this alloy is that it is entirely free from SCC problems. Moreover, it is easier to fabricate than zirconium. Therefore, Ti-5Ta alloy is now seen as the most promising future material for nuclear fuel reprocessing application.[6)]

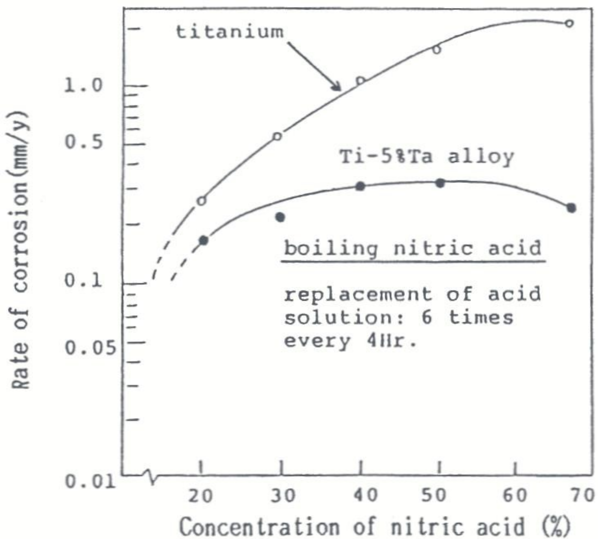


Fig.5 Rate of corrosion of Ti and Ti-5%Ta alloy in nitric acid

(4) Nuclear waste management program (Canister)

The reprocessing of spent nuclear leaves behind high-level radioactive waste which must be stored securely.

At present, spent nuclear fuel and high-level waste are temporally stored in indors, and stored in underground tunnels after a certain period of indoor storage is under consideration.

In this case, the waste would be put into metal canisters with an additional over-pack. However, due to the heat emission, the metal of such packing is expected to suffer from crevice corrosion.

ASTM Grade 12 (Ti-0.8Ni-0.3Mo, G12), which is resistant to high temperatures and crevice corrosion, is considered to be one of the candidate materials for such over-packing although there are a number of problems to be solved before making a decision on the underground storage of radioactive waste.

Wide coils, thick plates, and thin-wall seam-welded tubes produced from a large-scale ingot of G12 were investigated as to corrosion resistance, mechanical properties, weldability and so on. It was clarified that the G12 alloy has several advantageous features: the crevice corrosion resistance of the alloy was almost equal to those of G7 and PdO/TiO_2-coated Ti, and the maximum allowable stress was able to be designed higher than that of C.P.Ti. It is expected that industrial applications of the G12 alloy will increase owing to its low cost and high durability.

G12 wide coils and thin-wall welded tubes were manufactured on a commercial production basis, and corrosion resistance, physical properties, and weldability were investigated. It was confirmed that G12 provides far superior corrosion resistance, especially crevice corrosion resistance as shown in Fig.6, to C.P.Ti and has properties close to G7 and PdO/TiO_2-coated Ti. From the viewpoint of cost, G12 is less expensive than G7 or PdO/TiO_2-coated Ti.

In years to come, it is expected that G12 will replace C.P.Ti for prolongation of lite or to cut down the cost of G7 and PdO/TiO_2-coated Ti, and that the demand for G12 will increase.[7), 8)]

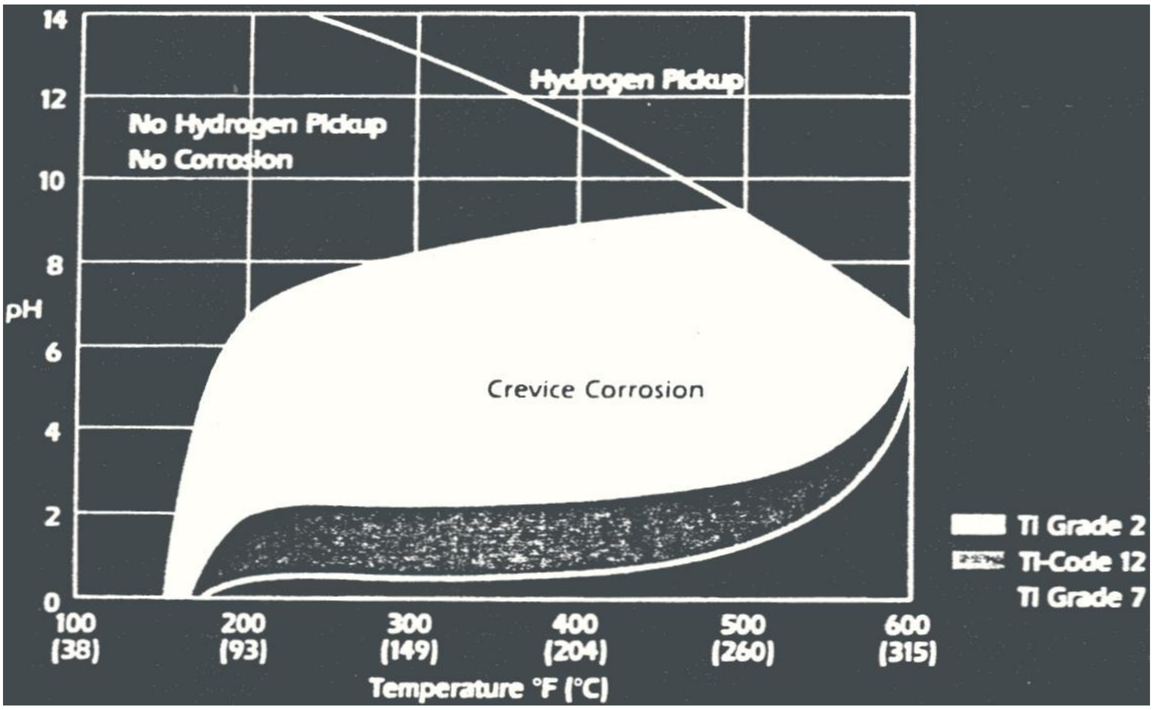


Fig.6 Crevice corrosion properties of Titanium Grades 2, 7 and 12 in saturated NaCl brine.[7)]

(5) Robota

Japan Atomic Energy Research Institute (JAERI) developed a prototype light-duty underwater manipulating Robot, as shown in Photo 5. of 10kg/100kg loading capacity employing Ti-6Al-4V made gear as form a part of JPDR reactor decommissioning technology.

The manipulator has high performance of seven freedoms of movement and seven hinges.

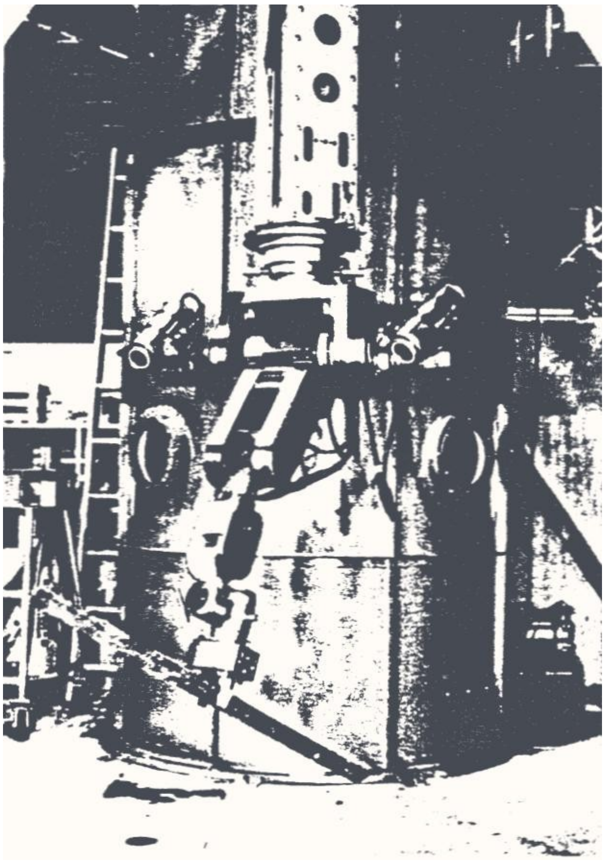


Photo 5 Outside view of Prototype light-duty underwater manipulator. Courtesy of JAERI and Mitsubishi H.I.

2. Automotive Parts

In 1989. Yamaha (Japan) adopted a surface-nitrided Ti-6Al-4V connecting-rod for a limited model of motorcycles (Photo 6). The parts have the most potential in automobile production model. The development of a low-cost, durable surface treatment and assurance of the material's durability are essential in order to use titanium and its alloy in automotive parts (Photo 7).

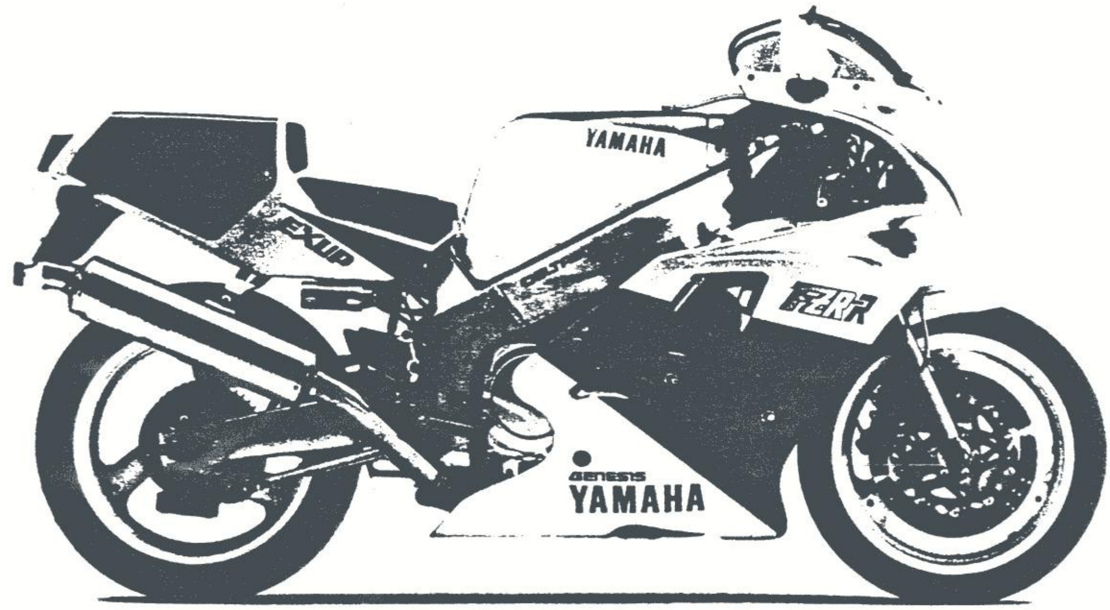


Photo 6 Yamaha FZR750-R Motorcycle
Courtesy of Yamaha Motor Co.

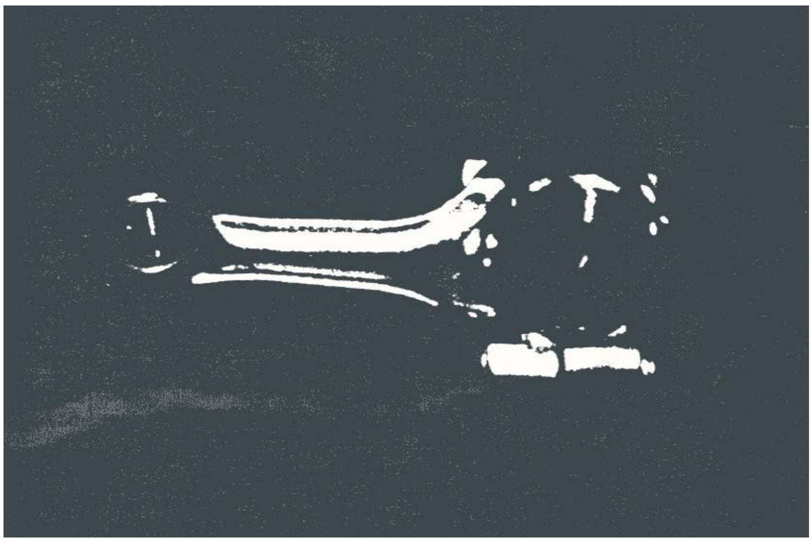


Photo 7 Ti-6Al-4V Connecting rod
ibid.

3. Personnel Pressure Hull for Deep-Sea Submersible

The first Japanese deep sea submersible of 2,000 m depth capability, named as "Shinkai 2000" was completed in 1981.

Continuously, Japan has constructed a deeper sea research submersible operating at or more than 6,000 m depth.

Research on technology to manufacture a titanium alloy pressure hull applicable to this submersible has been conducted by Mitsubishi Heavy Industries and assist with Kobe Steel.

Ti-6Al-4V ELI has been chosen for a pressure hull material because of the high strength-to-weight ratio, as shown in Table 3.

Ti-6Al-4V ELI 9-ton ingot was forged and rolled down to 110 mm thick plate to take a blank. The large plate was hot formed using a 13,000 ton press to make a hemisphere of 2,000 mm diameter. The primarily machined hemisphere was welded together with view ports and penetrator by electron beam welding method. Hemispheres could be electron beam welded together to sphere only for 18 minutes. Photo 8 shows a article "Shinkai 6500" having the 73.5 mm thick titanium alloy pressure hull.[9)]

Table 3 Strength-to-weight ratio of various materials for submersible pressure hull

Material	0.2% YS (kgf/mm^2)	Density (g/cm^3)	Strength-to-weight ratio
Ti-6Al-4V ELI	81	4.42	18.3
Ti-6Al-2Nb-1Ta	67	4.48	15.0
Fe-10Ni-8Co	120	7.85	15.3
NS90 Steel	90	7.85	11.5
SUS 316	18	7.98	2.3

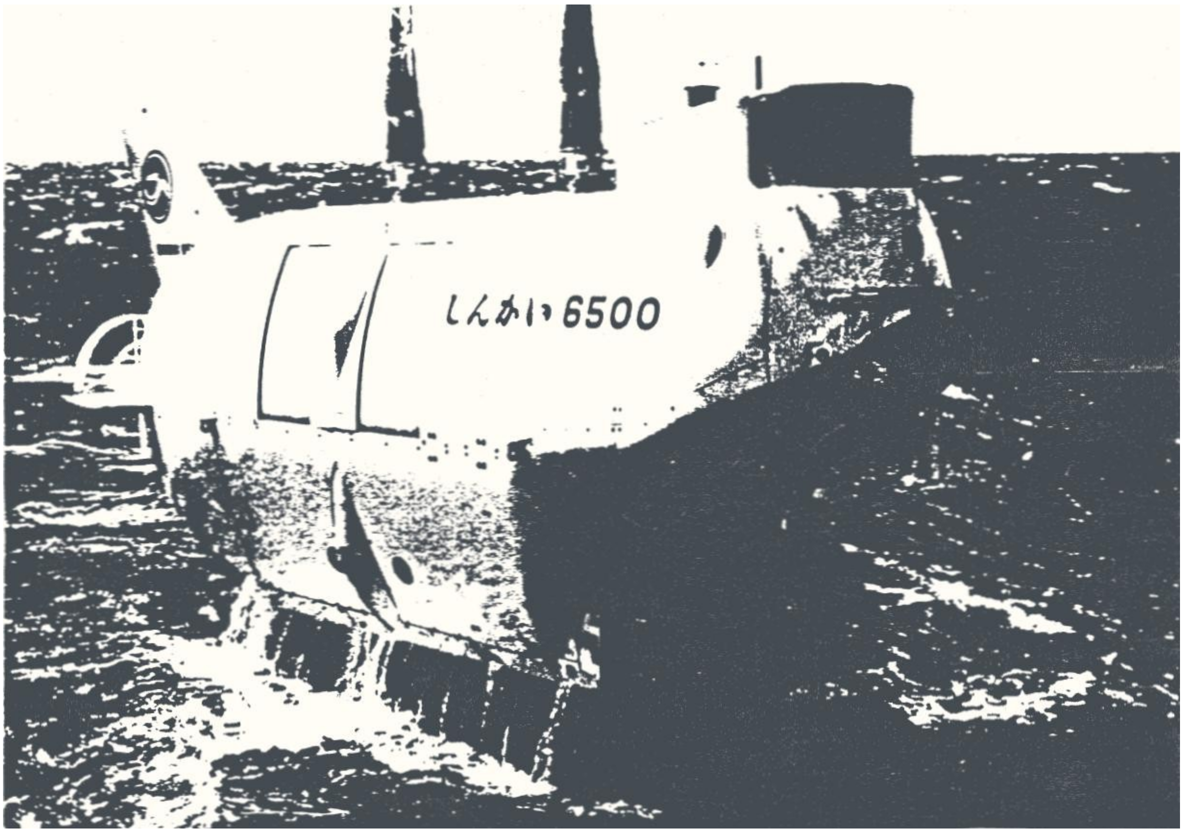


Photo 8 "Shinkai 6500"
Courtesy of Japan Marine Science and Technology Center and Kobe Shipyard & Machinery Works, Mitsubishi Havy Ind., Ltd.

4. Architecture and Civil Engineering

In Japan titanium has been used for sometime as a building material such as roofings, domes, curtainwalls, monuments, esteriors, interiors, etc. In 1987, about 12 tons of titanium sheets was used for the roofing of Kobe Municipal Aqua-life Museum as shown in Photo 9 and a magnificient sanctuary which used 90 tons of titanium was also erected.

Although titanium is still costly compared with the conventional high grade materials such as copper, aluminium and stainless steel it is attracting great interest of the people concerned as a new building material for the future not only because of its superior corrosion resistance but also because of its fashionable and artistic image.

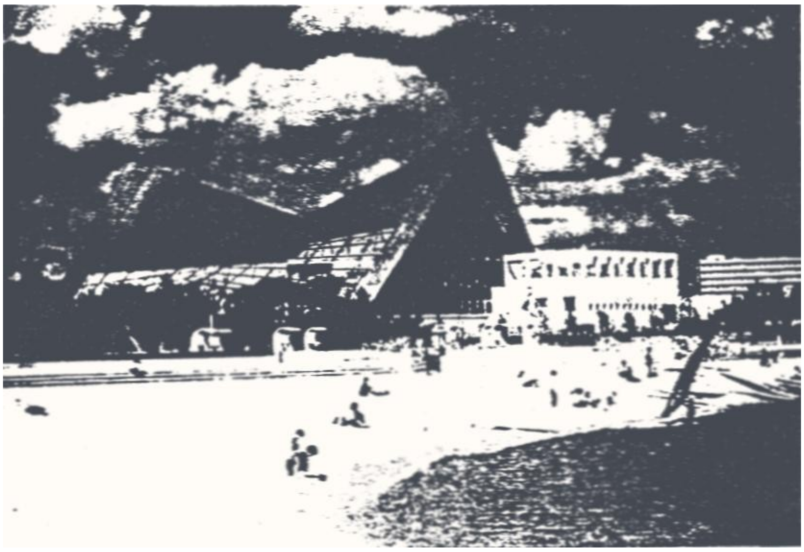


Photo 9 Kobe Municipal Aqua-life Museum at Suma with titanium roofing of 2,330 m^2 using 12 metric tons of titanium sheets of Kobe Steel.

Effects of various properties, every possible elastic and plastic tensile properties, grain size or impurity compositions on a magnitude of pocket waves were examined carefully. As a result, a magnitude of pocket waves was found to have a significant interrelation particularly with a grain size of original titanium sheet, as shown in Fig.6. It becomes evident that titanium sheets with finer grains (larger grain size number) are more effective in preventing the pocket waves. These specimens had the respective microstructures shown in Fig.7. It is clear that fine grained Specimen B has a superior appearance free from pocket waves compared to coarse grained Specimen A.

Various tests and investigations were made to construct the peculiar titanium roof of Suma Aqualife Park. Developed roll-forming technology and special titanium sheets for construction use were applied to the actual construction and satisfactory results were obtained. The special titanium sheets have given actual results in several other roofs including them of seam welded structure.

In future, the advantages of titanium such as corrosion resistance and easy maintenance will be confirmed. It is convinced that demand for titanium will expand more and more in construction field.[10)]

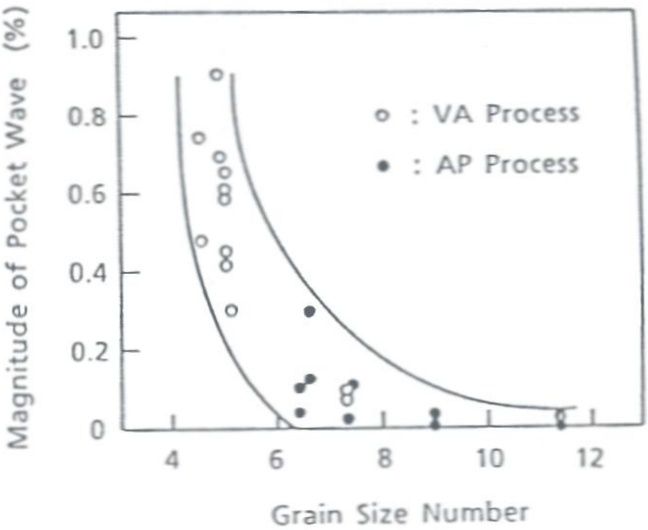


Fig.6 Relation between the magnitude of pocket waves and grain size number[10)]

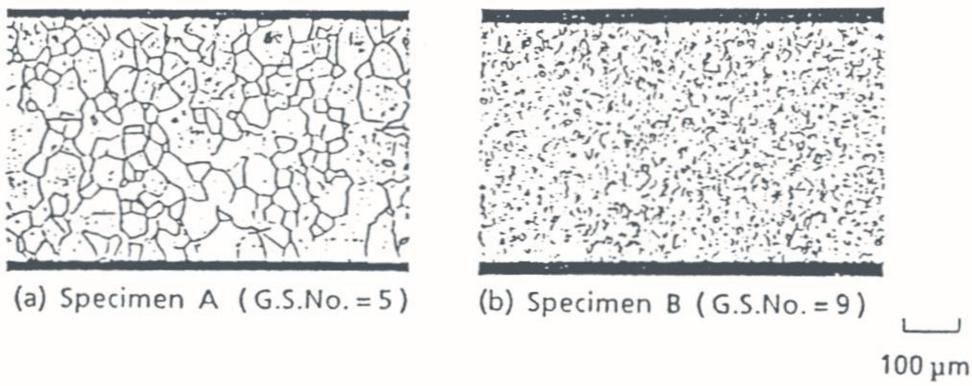


Fig.7 Microstructure of formed specimens [10)]

Epilogue

With its outstanding resistances to corrosion by seawater, comparable to that of platinum, titanium is also a "metal for the sea".

The field of ocean development, in which many of man's dreams for the future are being realized, encompasses an expanding variety of uses for titanium, such as equipment and components for ships, including deep-sea submergible vehicles, and equipments required for seabed resources, oil wells on continental sheives, off-shore fish farms, bridges across the sea, artificial islands, and cities on the sea.

In addition to these uses, titanium is also used for its beauty and other special features in the manufacture of articles of daily necessity, including eyeglass frames, cameras, writing instruments, cigarette lighters, jewelry, and a variety of sports goods, such as tennis and badminton racket frames, golf club shafts, bicycles, motorcycles, yachts and mountain-climbing equipment.

Because of its bioacceptability, titanium is also attracting attention as a material for the manufacture of articles for medical purposes, such as artificial bones, artificial dental implants and heart pacemakers, thus indicating that the metal is bound to become an indispensable material as the elderly population continues to increase.

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