NONAEROSPACE APPLICATIONS OF TITANIUM

Y. FUKUHARA

Kobe Steel, Ltd. 1-8-2 Marunouchi, Chiyoda, Tokyo, Japan

(keynote lecture)

1. Introduction

Applications of titanium can be classified into aerospace and nonaerospace. Initially, in the USA titanium was mostly used for aerospace applications, and from there its nonaerospace applications have gradually increased. Conversely, in Japan, titanium was used entirely for nonaerospace initially. Recently, however, its aerospace applications are on the increase. In Europe, both applications, aerospace and nonaerospace, have grown almost simultaneously. The situations in other countries may be similar to that of Europe.

Aerospace applications will continue to increase steadily, although a sharp expansion cannot be expected. On the other hand, nonaerospace applications, which are extremely varied, can be expected to increase greatly in the future. Titanium is still an expensive metal, but the expansion of its overall consumption will entail a reduction of cost which in turn will bring about a further expansion in consumption. Typical nonaerospace applications are chemical plants, condensers for power generation, desalination plants, electrodes, biomedical applications, offshore and marine structures, steam turbine blades, architecture, automotive parts, sporting goods, etc.

In this lecture, the recent status of these new applications in Japan will be discussed particularly architectural applications. Moreover, the problems that need to be solved to allow further expansion of nonaerospace applications will be described. However, applications for biomedical and corrosion problems are not delved deeply into here, as another speaker will give a keynote lecture on these subjects.

2. Trends in Consumption

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

Originally, titanium was used frequently in petrochemical plants. However, as investment in plant and equipment in this field slowed down, the consumption of titanium also decreased. The next application was in condensers for power generation especially in nuclear power plants, where in most cases dependable titanium was used. However, with the sluggish growth rate of the world economy, the construction pace of power plants has dropped, and titanium consumption in this field has reached a ceiling. However, the construction of power plants continues in Asia, particularly in China, and here titanium consumption is also increasing.

From the latter half of the 1970's to the first half of the 1980's, the construction of desalination plants was actively carried out in the Middle East and titanium was used in very large quantities. In a certain desalination plant, as much as 1300 tons of titanium was employed. In this field likewise, however, the sharp rise in titanium prices that started in 1979, and the subsequent drop in crude oil prices which brought on the economic decline of the Middle East countries, resulted in a sharp drop in titanium consumption in this area. Once titanium has been replaced by copper alloy, it requires considerable effort to revert to the titanium design.

Caustic soda and chlorine are the basic raw materials of the chemical in-
Titanium is indispensable in the manufacture of equipment for the production of terephthalic acid (TPA), urea, acetaldehyde, acetone, chlorine gas, acetic acid, etc. It is also in constant demand for oil refining, fiber dyeing equipment, pulp manufacturing equipment and metal plating equipment. Titanium is crevice corrosion resistant, but is susceptible to crevice corrosion at high Cl-ion concentration and high temperatures. It is known that the resistance of titanium against crevice corrosion is improved by the addition of about 0.1% Pd. As Pd is extremely expensive, ASTM Grade 12 (Ti-0.8 Ni-0.3Mo) has been developed in the USA. This alloy is not only resistant to crevice corrosion but is also, due to its great strength at high temperatures, a material suitable for environments with high Cl ion concentration at high temperatures. By employing this material it is possible to reduce...
the equipment cost due to the thinness of the material. Further, since the ASTM Grade 9 (Ti-3Al-2.5V) is relatively easy to fabricate and has higher strength at high temperatures than the Grade 12, it is suitable for high-temperature applications, but is not put to practical use, because it is not yet specified in the ASME Code. In order to get it specified in the ASME Code, it is necessary to apply to the ASME with engineering data for this metal. Metal manufacturers are requested to work together to provide such engineering data.

Soft-drink containers are undergoing a change from glass bottles to metal cans; however, recently plastic (TPA) bottles resembling glass bottles have come into use. In the manufacturing equipment of TPA, a large quantity of titanium is used.

3.2 The Energy Industry

In the main condensers of nuclear power plants, which should be free from sea water leakage, fully-titanium tubed condensers are normally employed. Recently, due to the maintenance-free feature of fully-titanium tubed condensers, it has become to be used in thermal power plants as well. Titanium, though resistant against erosion, erosion due to droplet impingement on the outer surface of top tubes on the cold end side in the tube bundle was found in a certain country. To counter this problem, it is necessary to investigate such measures as making the wall thickness of top section tubes thicker or using titanium tubes of higher hardness. There is no difference between the rate of growth of marine organisms and slime on titanium tubes and aluminum brass tubes at a flow rate of 2.6 m/sec, however the difference is pronounced at a flow rate of 2.0 m/sec.

Because of pollution, chlorine injection is prohibited, and so cleanliness is maintained by sponge-ball cleaning and reverse-washing. At present, sponge balls of standard hardness are employed, but where insufficient cleanliness is obtained, the use of carborundum-impregnated balls or granular balls needs to be investigated.

In boiling-water type reactors, it is said that free hydrogen is generated in a slight quantity due to the dissolution of water by radiation. However, periodical inspection in Japan has proved that titanium condenser tubes are free from the risk of hydrogen absorption.

In the fully-titanium-tubed condensers of Japanese power plants, solid titanium tube sheets are generally employed, though in the USA and Europe, titanium clad steel is mostly used. Tube sheets made of clad steel plate have an advantage in that tube sheets and shells can be welded together. The clad steel plate is made by an explosive cladding process.

However, since large clad plates are not available, tube sheets made of the clad steel plate are welded together. In Japan, in order to make large clad steel plate, development of a rolled clad steel plate is under way. Although a clad steel plate of about 4 m wide has already been made successfully, it is not yet available for use in power plants. If its reliability is verified, rolled clad steel will certainly be used in the same way as tube sheets in the near future. Rolled clad steel plate is manufactured as follows: The steel slab as base metal, interface metal, and titanium plate are packed into a vacuum tight steel box which is then evacuated and sealed. The box is heated and hot rolled. The hot rolled box is cut out and the titanium clad steel plate is taken out of the box. A thin box will break during rolling, therefore, so fairly thick steel plates have to be used, which make the rolled clad steel more costly than anticipated. In a nuclear power plant, besides the main condensers, a number of heat

![Fig. 2 Construction of pack for titanium clad steel](image)
exchangers are used, and most of the heat exchangers are plate type and made of titanium.

General Electric Co. has used titanium alloy in steam turbine closing blades. In 12% Cr steel, a corrosion problem has occurred, and an investigation into changing all the L-1 stage blades into titanium alloy has been carried out in the USA and Europe. The application of titanium alloy blades in the final stage will not only solve the corrosion problem but will permit larger blade lengths to be made thus contributing towards improving the turbine efficiency. It is said that BBC, Alsthom Atlantique, Thyssen, VEW, as well as LMZ of USSR and WH of USA have already succeeded in the trial production of long Ti-6Al-4V blades. A certain electric power company in Japan has developed 40-inch blades in cooperation with a turbine manufacturer, and has discovered that, compared with 33.5-inch Cr-steel blades, a 1.5% improvement in thermal efficiency and cost saving of several million dollars a year are possible. In a 700 MW thermal power plant scheduled for commercial operation in 1991, 40-inch blades will be employed. Since the blades call for a high fatigue strength, Jaffee and Luetjering are proposing a bimodal microstructure.

In the USA, spent nuclear fuel in nuclear power plants is stored without any special processing. In other countries, however, it is reprocessed to be reused as nuclear fuel. The reprocessing is carried out by Purex process using nitric acid. At first, the reprocessing equipment was made of stainless steel, more recently, the use of zirconium has been tried.

The Ti-5Ta alloy is easy to manufacture and has excellent corrosion resistance as shown in Fig. 12. It is also immune to stress corrosion cracking and therefore, it was recently decided in Japan to apply this alloy to some of the reprocessing equipment. The reprocessing of spent nuclear fuel leaves behind high-level radioactive waste which must be stored securely. At present, spent nuclear fuel and high-level waste are temporarily stored indoors, and storage in underground tunnels after a certain period of indoor storage is under consideration. In this case, the waste will be put into metal canisters with an additional over-pack. However, because of the heat emission, the metal of such package is expected to suffer from crevice corrosion. As the material for such over-pack, the ASTM Grade 12, which is resistant to high temperatures and crevice corrosion, is considered to be one of the candidate material, although there are still a number of problems to be solved before making a decision on the underground storage of radioactive waste.

For instance, as regards corrosion, though a measurement in the order of 0.01 mm/year has been obtained so far, a study of microcorrosion in the order of 1/100 is also necessary. Therefore, it will be fairly far in the future before titanium is used in this area.

In the USA which has a large number of coal-fired thermal power plants, high-sulfur coal is used, thus causing the problem of acid rain. As a countermeasure, the fuel gas desulfurization is made and titanium is suited for the desulfurization equipment. The use of titanium in this area is on the increase.
A low-fin titanium tube was first developed in the USA, and this tube is used in the liquefying equipment of natural gas and the district heating equipment using underground water.

The USA has a considerable number of natural gas collecting wells. These are made from high-nickel alloy and stainless steel and are exposed to high temperatures and corrosion. As a substitute for high-nickel alloy, beta titanium alloy has considerable potential because it is superior in such features as its light weight, high strength and high corrosion resistance. However, because of lack of interest in energy exploration, it has not been put into practical use.

Since the stress joints of offshore oil wells are subjected to pulsating stress from waves, titanium alloy, which is of low Young's modulus and high strength and excellent in corrosion resistance is the ideal material. RMI and Cameron made stress joints for trial using an extrusion process. These joints are now undergoing tests.
3.3 Automotive Parts

Titanium alloy, which is both light and strong, has attracted attention for a long time as material for automotive parts, and it is used extensively in race cars. Porsche reports that titanium alloy has been used extensively not only in engine parts but also in drive systems and suspension springs. In the USA, Ford has been investigating the use of titanium in valve systems and suspension springs. However, no automobile manufacturer has used titanium in production models as yet.

In 1987, Honda (Japan) adopted a titanium connecting rod for its limited model of motorcycles. The parts which have the most potential in automobile production models are valves and valve retainers. The development of a low-cost and durable surface treatment and assurance of the material's durability are essential in order to use titanium in automotive parts.

![Fig. 6 Titanium engine parts used for Porsche race car](image-url)
3.4 Biomedical Applications

In the USA instead of using routine insulin injections for diabetics, an implant using a titanium pump is being tried out and seems to be getting good results.

IMI and Sulzer are developing Ti-Fe and Ti-Nb series titanium alloys which give better biocompatibility.

A titanium implant with a roughened surface to improve physical anchoring and coated with ceramic or glass of good biocompatibility to promote bone growth is under development. For the biomedical application, another lecturer will give a keynote lecture.

3.5 Architecture

In Japan, titanium has been used for sometime as a building material, and at the International Conference of 1984, a project which would use about 2 tons of titanium for roofing was presented. In 1987, about 12 tons of titanium were used in the roof of Kobe Municipal Aquarium, and sanctuary which used about 90 tons of titanium was also erected.

In Japan’s Okinawa islands, where strong hot sea winds prevail, aluminum and stainless steel cannot withstand the corrosive weather.

Salty moisture which gets into the gaps of roofing is condensed by the heat of the sunlight and this corrodes the metal. Therefore, titanium is attracting great interest as a building material. Although titanium is still costly as compared with stainless steel, it is considered to be cost effective because of its long life and the elimination of repair work. One of the promising markets is the area around the Arabian Gulf where the weather conditions are similar to those of Okinawa.

Fig. 7 A sanctuary roofed with titanium (courtesy of Nippon Steel)
3.6 Other Applications

In the USA, ASTRO have developed an extremely compact, small-sized heat exchanger that looks promising as a cooler for precision equipment such as computers. In the snow-belt area of the Northern Hemisphere, salt is sprayed on the roads in winter, and therefore corrosion problems have occurred to the reinforcing steel bars of roads and bridges.

As a countermeasure, cathodic protection for steel bars is being considered, and IMI is investigating a method of using a titanium net as the anode. If this process is successful, demand for a considerable quantity of titanium may be expected.

Golf clubs and tennis rackets made of titanium have not become as popular as those made of composite materials, which seem to be more suitable for these areas. As a material for sporting goods, titanium would be more suitable for yacht and motorboat parts.

In Japan, titanium is used for making compression tools for electric wire connections at elevated spots and also promises to be useful for tools used for high-elevation work.
Finally, a heat exchanger as technically advanced as today's lasers.

Fig.10 Ultra-compact titanium heat exchanger (courtesy of ASTRO)

Fig.11 Titanium nets used for cathodic protection of steel reinforce bar (courtesy of IMI)

Fig.12 Compression tool made of titanium alloy (courtesy of Izumi Precision Works)
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