UDC669.295.7:681.43:641.546.26:629.118.3

Application of Titanium to Eyeglass Frames, Vacuum Bottles, and Other Consumer Goods

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Abstract:

The consumer goods market is steadily expanding and now comprises a wide variety of products. Consumer goods are manufactured in small lots and diverse product types. While titanium is used mainly in industries, its application to consumer goods is expected to stimulate repetitive demand for it as consumers become familiar with it. Properties required of titanium vary with the type of consumer goods to be made from it. What are common to all such consumer goods are titanium application and fabrication technology centering on joining technology and such surface treatment technology as grinding and polishing. This paper outlines the past application of titanium to consumer goods, and the history of development of some pertinent consumer goods with solutions to technical problems encountered in the way.

1. Introduction

Application to consumer goods has special significance in the market development for titanium. As compared with such mass demand sectors as construction, civil engineering, automobiles and marine engineering, the consumer goods market requires small-lot production of diverse product types on the part of manufacturers, but on the other hand has the nature of stimulating repetitive demand as consumers familiarize themselves with the some products through everyday use.

Recently, the consumer goods market has grown to a scale of 300 tons of titanium use per year. Consumer goods made from titanium run a wide spectrum of products from conventional accessories like eyeglass frames to sporting goods and household utensils (see **Fig. 1** and **Table 1**).

Among those consumer products using titanium, eyeglass frames pioneer the accessories bracket. Since titanium eyeglass frames were commercialized about 10 years ago, they have steadily grown in output and are now estimated to account for about 30% of eyeglass frames, constituting a titanium market of about 100 tons per year. Considering the problem of metal allergy high-

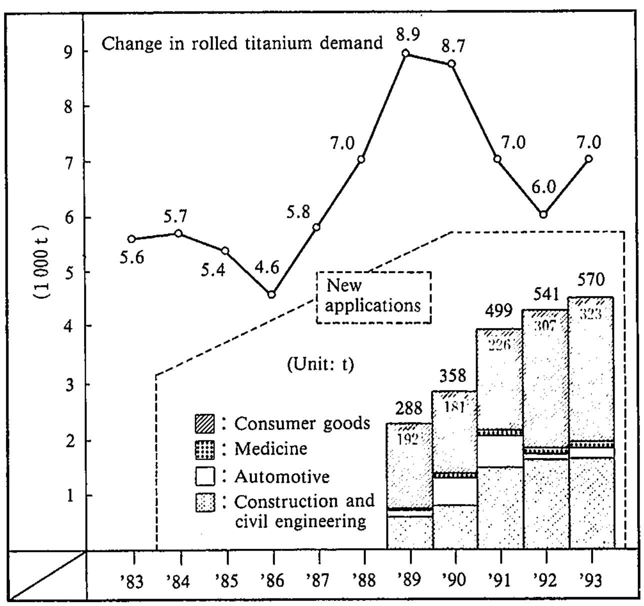

Fig. 1 Transition of demand in new titanium market

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Table 1 Estimate of titanium demand by type of consumer goods

Class	Product	Titanium	Shape	Quantity (t)	Remarks
Personal goods	Eyeglass frames	CP, alloy	Wire	80-90	
	Wristwatch bands	CP	Sheet	40-50	
	Wristwatch cases	CP, alloy	Plate	30-40	
	Ornaments, etc.	CP		8-15	Accessories, cameras, etc.
Sporting goods	Golf clubs	Alloy, CP	Round bar	50-60	
	Bicycles	CP, alloy	Tube	5-10	Mountain bikes
	Others	CP, alloy		5-10	Spikes, kendo face protector grills
Household utensils	Containers	CP	Sheet	3-5	Chinese cooking pans, vacuum bottles, etc.
	Tools	Alloy	Rod	3-5	
	Others	CP	Rod	8-15	Fish nursary nets, etc.
Total				300	

CP: Commercially pure titanium

lighted recently, the titanium use in eyeglass frames is expected to increase further. The metal allergy issue has contributed to the substitution of titanium in wristwatch cases and bands. Its light weight and non-allergy causing property are important factors in the current titanium boom for wristwatches. Anodizing-colored titanium is used in such ornaments as ear rings and necktie pins, and titanium sheet is used in high-class camera bodies. The total titanium consumption in such consumer goods as eyeglass frames and camera bodies is put at about 200 tons per year.

In the titanium use in sporting goods, titanium golf clubs are strong selling goods of late. Its low Young's modulus is best exploited in this application. Mountain bike frames and bolts are now looked upon as a very promising area of demand growth for titanium. Titanium is used in small amounts in such sporting goods as kendo face protector grills, baseball shoe spikes, and fishing goods. The titanium tonnage used in sporting goods is estimated at about 80 tons per year.

Titanium is used in such household utensils as Chinese cooking pans, frying pans and other cooking utensils, vacuum bottles, sake liquor bottles, whiskey scuttles, and other containers. Cooking utensils and containers made of titanium are mainly intended for professional use or high-class social use.

Application of titanium to tools is steadily increasing. Safety hooks, large spanners and wrenches made of titanium alloys are very light and nonmagnetic compared with those made of steel, which lessens danger during work at elevated places.

Aquacultural nets are an attractive application field where titanium is expected to find increasing usage. Conventional nets are mostly made of heavily galvanized steel wire or chemical fiber. They involve several problems, such as low durability, low corrosion resistance and offshore disposal, and must be replaced every two years. Recently, there has been mounting demand for aquacultural nets made of new materials. Titanium nets have been under test use at several fish farms, and have proved reliable in more than 18 years of test. They are expected to find widespread application. Consumer goods centering on household utensils now use only about 20 to 30 tons of titanium every year, but this figure is expected to grow fast in the future particularly in such applications as fish nursery nets.

The use of titanium is on the increase also in medical equipment applications. Particularly, the substitution of titanium for steel in wheelchairs offers a large weight saving and is considered to be helpful in lessening the burden on wheelchair users.

Titanium applications to consumer goods have been outlined above. Nippon Steel has selected consumer goods for which the use of titanium is to be explored, and accordingly has carried out development work jointly with affiliated manufacturers, with particular attention paid to the following requirements:

(1) The consumer goods best exploit the characteristics of titanium and are designed to be placed in physical contact with the users.
(2) They are not high-class limited-volume products but commonly used products.
(3) They are friendly with users and the environment.
(4) They can be offered in large lot sizes.

Eyeglass frames, mountain bikes, and vacuum bottles are described below as typical consumer goods developed for titanium application.

2. Titanium Eyeglass Frames

2.1 Eyeglass frame market

In 1905, Japan's first eyeglasses were made in Fukui, and 67 years later in 1972, Nikon conceived the use of titanium in eyeglass frames for the first time in the world. Titanium eyeglass frames exhibited at the Japan Eyeglasses Exhibition held in Fukui City in October 1982, brought about an epochal change in the domestic eyeglasses market, and won the first place among metal eyeglass frames four years later. Of 30 to 40 million eyeglass frames produced per year, titanium frames account for about 30% will a total of about 10 to 12 millions annually. Since titanium frames weigh 8 to 13 g per piece, they constitute a domestic titanium demand of about 100 tons. In recent years, titanium frame manufacturers have been focusing their efforts on exports. Particularly in Europe, the problem of nickel allergy, or the ill effect of nickel on the skin is much talked about, and this is expected to accelerate the use of titanium in eyeglass frames in the future[1-3].

2.2 Application of titanium to eyeglass frames; problems

Eyeglass frame materials must clear many property constraints, including light weight, strength, corrosion resistance, formability, and surface treatability. Eyeglass frames have been historically made of iron, copper, nickel, and titanium in that order. Commercially pure titanium was initially used in eyeglass frames, and commercially pure high-strength titanium (TIX) was

Table 2 Property evaluation of rim wire materials

Material	Conditions	Tensile strength (kgf/mm^2)	Formability	Strength		Platability	Braze strength
				Evaluation	Number of cycles to failure		
CP Ti	Ann	35-52	○	×	300	◎	○
10Zr	Ann	55	○	△	903	△	◎
TIX-80	Ann	80	×	△	1,144	○	◎
3Al-2.5V	Ann	88-	○	○	1,581	△	◎
22V-4Al			○	◎	5,000	◎	◎
15V-3Cr-3Sn-3Al	ST	72-92	○	◎	5,862	◎	◎

Ann: Annealed, ST: Solution treated

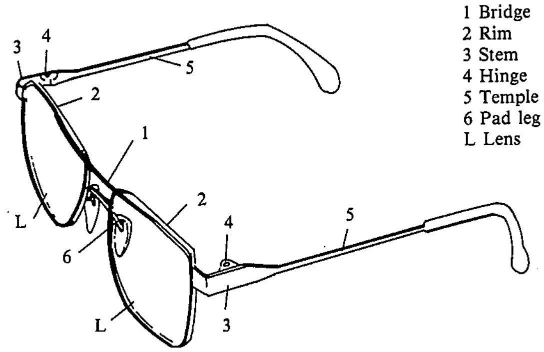

Fig. 2 Eyeglass frame parts

then studied for its high strength and 950°C transformation temperature. More recently, commercially pure titanium is giving place to the half alloy (Ti-3Al-2.5V) with good drawability, and beta alloys with good cold workability and no phase transformation. These types of titanium alloys were comparatively investigated for rim wire formability, number of cycles to rim failure, platability and brazed joint strength, among other properties. The results are given in **Table 2**[4].

The eyeglass frame consists of temples, a bridge, rims, stems, hinges and pad legs, as shown in **Fig. 2**, and has at least 14 brazes. This calls for the development of a reliable brazing method that solves the problem of dissimilar metal joining. A strong titanium brazed joint cannot be obtained unless the surface oxide film is removed and the active surface is exposed to receive the filler metal. Flux is commonly used to braze other metals. Since titanium has no practical flux available, it is brazed in an argon gas shield using a Ti-Cr-Ni or Ag-Cu filler metal. The Ti-Cr-Ni and Ag-Cu filler metals have high transformation temperatures of 950 to 1,000°C and 890°C, respectively, and when either of them is used to braze pure titanium that is lower in transformation temperature at 880°C, the heat-affected zone (HAZ) of brazed joints tends to coarsen in grain size to lose its strength, leading to a failure. Grooved rims are especially susceptible to such cracking. Take the brazing of the rim and pad leg for example. The brazing procedure varies with the material of the leg as follows. When the leg is made of nickel-brass alloy, it is brazed by applying the Ag-Cu filler metal to the titanium rim surface that is roughened and plated with 30 μm of dull nickel. When the leg is also made of titanium, it is brazed to the rim using a titanium filler metal or spot welded to the rim in an argon shield. Other measures now under study include brazing temperature measurement with an infrared radiation pyrometer, electric current control, and study of low-temperature filler metals.

3. Development of Titanium Bicycles

3.1 Outline of bicycle market

Japan's domestic bicycle demand has surpassed 8 million units annually in the past several years, of which more than 90%, namely, 7.45 million units, was produced in Japan in 1992. When classified by type, light bicycles account for about a half of the total production, followed by mini-cycles, mountain bikes, and sports bicycles in that order. The mountain bike demand has increased to the order of 1 million units per year. Bicycle frames have been conventionally made of chromium-molybdenum steel or super duralumin. Recently, the weight of bicycles, mainly mountain bikes, has been reduced by making use of the high specific strength of titanium. Titanium frames were initially made by hand for the most part, and bicycles with titanium frames were introduced into the marketplace as high-class limited-volume bicycles. Recently, leading bicycle manufacturers have devised titanium joining methods and accomplished cost savings, as a result of which titanium-framed bicycles are expanding its market and are expected to increase further in the future.

3.2 Properties required of bicycle frame titanium

Bicycle frames are mainly made of chromium-molybdenum steel pipe with a tensile strength of more than 85 kgf/mm^2 and wall thickness of 1.0 to 1.2 mm. When made of titanium pipe with approximately the same tensile strength and wall thickness as the steel pipe, prototype bicycle frames performed better than specified in the applicable Japanese Industrial Standard (JIS). This high-strength thick-walled titanium pipe can be made by the seamless process, but is not competitive enough in terms of price and has such surface roughness that it is very time-consuming to grind the product frames. Answering the essential need for cost-competitive welded pipe of titanium, Nippon Steel has been providing bicycle manufactures with high-strength, thick-walled, and small-diameter welded pipe of titanium.

3.3 High-strength titanium bolts for bicycles

Bolts for bicycles come in either cut-thread bolts or rolled-thread bolts. Commercially pure titanium has been used to produce both cut-thread bolts and rolled-thread bolts. It is well known that rolled-thread bolts outperform cut-thread bolts. For higher bolt strength, high-strength titanium bolts are made by hot forging the Ti-6Al-4V alloy into bolts and cutting threads on the bolts. This process was very expensive, however, and relatively inexpensive high-strength titanium bolts have been sought for high-class bicycle parts[5]. Decorative bolts (hexagon socket and flange head bolts) have been made by the thread rolling process from Ti-3Al-8V-6Cr-4Mo-4Zr (Beta C) alloy bars and supplied as genuine parts for high-class bicycles.

In the process comprising VAR melting, hot forging, rod rolling, grinding, peeling, straightening, cutting, polishing and inspecting, Beta C alloy bars, measuring 9.1 mm in diameter (+0, −0.04 mm) and 2,000 mm long, are first solution heat treated. The grinding step is skipped to proceed from the rod rolling step directly to the die peeling step. More drastic process simplification will take place in the future.

Decorative bolts (hexagon socket and flange head bolts) used for attaching the bicycle pedals to the crank are made by upsetting and machining the head, rolling threads, and heat treating (aging) the bolt. Cold-rolled bolts produced by this process were aged at 500°C to a friction coefficient of 0.15 to 0.20. When their tightening torque was then measured, it turned out to be 800 kgf·cm for exceeding the specified value of 600 kgf·cm.

4. Development of Titanium Vacuum Bottles

4.1 Background

In the past several years, Japan's domestic vacuum bottle market has grown thanks to the outdoor boom. In particular, the proportion of stainless steel vacuum bottles has been rapidly growing. Against this background, Nippon Steel conducted joint work on the development of titanium vacuum bottles with Nippon Sanso who had developed stainless steel vacuum bottles. The first target of the joint development work was a large 2,000-ml titanium vacuum bottle. As its outside diameter was relatively large, the 2,000-ml vacuum bottle could be easily formed from JIS Class 1 commercially pure titanium. The next target was a slim 450-ml titanium vacuum bottle of sophisticated design, designated "Shuttle Titanium" and small enough to be carried in an attache case. The Shuttle Titanium consists of five parts. The material dimensions of the five parts are given in **Table 3**.

The performance of vacuum bottles is specified by heat insulation and impact resistance in JIS S 2053. The heat insulation performance of the Shuttle Titanium was determined by pouring 95°C hot water into it and measuring the hot water temperature 24 hours later. The temperature was 43 to 45°C when the inner case thickness was 0.4 mm and 47°C when the inner case thickness was 0.3 mm. Each value satisfied the JIS requirement of > 42°C. In the drop test designed to check impact resistance, the Shuttle Titanium, party became of its small size, successfully met the specified value. The Shuttle Titanium was hairline finished to make fingerprints unnoticeable or was wet polished with the abrasive introduced in Reference[6]. It is offered in a leather bag and a cardboard case to appeal to the increasingly discriminative users.

4.2 Manufacture of Vacuum Bottles

The inner case, inner case bottom, and outer case bottom are bent, inert gas tungsten arc welded, and drawn. These parts are relatively easily manufactured in Tsubame City of Niigata Prefecture, an area famous for its metal flatware manufacturing industry. The outer case and cup encountered the following problems, especially in the mass production stage. Considerable energies were expended in solving the problems.

Table 3 Material dimensions of vacuum bottle "Shuttle Titanium"

Part	Specification	Material dimensions (mm)	Weight (g)
Inner case wall	TP28C	0.3 × 270 × 270	98
Inner case bottom	TP28C	0.4 × 105 × 105	20
Cup	TP28C	0.4 × 140 × 140	35
Outer case wall	TP28C	0.5 × 300 × 420	284
Outer case bottom	TP28C	0.5 × 70 × 70	11
Total			448

The brazing filler metal used for vacuum sealing was developed after repeated experiments at Nippon Steel's Steel Research Laboratories. A patent is pending for the filler metal.

4.2.1 Forming of outer case

The outer case was formed as follows. A 0.5-mm thick titanium sheet was blanked into a fan shape, tungsten inert gas arc welded into a cone, and expanded by 8 to 16% in a press. The expanding operation resulted in weld cracks for the following reasons:

(a) The yield strength of titanium was 21 kgf/mm^2 and lower than 24 kgf/mm^2 for the JIS SUS 304 stainless steel.

(b) The springback of titanium was so large that the blank could not be curled with three rolls. Young's modulus of titanium was 10,850 kgf/mm^2 against 20,400 kgf/mm^2 for the JIS SUS 304 stainless steel.

(c) The argon gas shield during tungsten inert gas arc welding (TIG) was not complete.

Problems (a) and (b) were solved by specifying the transverse yield strength of the titanium blank at more than 22 kgf/mm^2 (against the JIS requirement of 17 kgf/mm^2 or more), measuring and controlling the roundness of the cross section of the curled case, and improving the TIG groove. For problem (c), the welding speed was lowered, and the argon gas shield was modified to improve the weld bead shape and raise the bond strength. In addition, the number of bulging dies in the expanding step after the TIG step was increased to 5 from 3 for the JIS SUS 304 stainless steel, reducing the severity of forming per die. Warm forming and post-weld annealing at 700°C were found to allow expansion to 38% on a test basis.

4.2.2 Forming of cup

The cup is made by deep drawing a circular blank on a cold crank press. The cup was successfully formed through the following measures:

(a) The titanium sheet surface roughness and thickness tolerance were improved.

(b) The 125-mm diameter blank was deep drawn in two stages (125 mm diameter → 70 mm diameter × 45 mm height → 60 to 55 mm diameter × 55 mm height).

(c) A 60-μm thick Teflon sheet was used for lubrication.

4.2.3 Plating of inner case and development of low-temperature brazing filler metal

The inner case was copper plated to alleviate the temperature drop arising from radiative heat transfer. The brazing heat diffused titanium and discolor the copper plating. If 20 μm of copper is plated on a 1-μm nickel preplate, the copper color can be retained at the brazing temperature of 730°C. Nippon Steel's Steel Research Laboratories improved the Ag-Cu filler metal into a ring-shaped filler metal for brazing at 700°C or less. The effectiveness of the new filler metal is introduced in Reference [7].

5. Conclusions

Commercially pure titanium is being replaced by titanium alloys in new consumer goods applications. Generally, high-strength titanium is very low in stock and is extremely difficult to procure for prototype fabrication. Use of TIMET titanium alloys will have to be considered. Even if a prototype of the product has been realized, its commercialization will require the ingenuity of both Nippon Steel and customers to nurture a stable demand for it. It is certain that new consumer goods made from titanium will be developed only through the incessant effort and great enthusiasm of those concerned in and out of the company.

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