APPLICATIONS OF TITANIUM AND TITANIUM ALLOYS
A. Commercially Pure Titanium in Surface Condensers and Chemical Equipment
LARGE TITANIUM-TUBED CONDENSERS WITH WELDED TUBE-TO-TUBESHEET JOINTS

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Introduction

It is a well-known fact that titanium possesses excellent characteristics as tube material for condensers that use seawater as coolant. One report states that titanium-tubed condensers, having been in operation in the United States and other countries for several years, have achieved satisfactory results. In these so-called "titanium-tubed condensers," the condenser tube is definitely made of titanium. However, the tubesheet is copper alloy, such as naval brass and muntz metal, jointed to the condenser tube by a rolled joint. Generally, thin titanium tubes are employed, which result in reducing tube-holding power of the tubesheet. Depending on the operating condition, therefore, it becomes difficult to achieve sufficient joint strength and complete airtightness.

To completely remedy this defect of titanium-tubed condensers, it has proved to be ideal to use titanium plate or titanium-clad steel plate for tubesheets to achieve welded tube-to-tubesheet joints.

However, it had been complicated to produce a titanium-tubed condenser with welded tube-to-tubesheet joints (hereinafter abbreviated to welded-type titanium condenser) because (1) it is difficult to ensure an extremely clean environment for welding operations required by titanium welding at power plant construction sites; (2) hardships are encountered in manufacturing large-sized titanium plates; and (3) this type of condenser is very expensive.

In defiance of these difficulties, Toshiba has successfully completed three units of welded-type titanium condensers--two units for a 600MW fossil power plant and one unit for a 1100MW nuclear power plant. Among these three units, the two units for the fossil power plant have proven to be satisfactory under test runs. We are convinced that welded-type titanium condensers manufactured by Toshiba cannot be exaggerated to be regarded as "ideal condensers."

This paper described the details of Toshiba welded-type titanium condensers from design to completion of production.

Design of Welded-Type Titanium Condensers

Table I lists specifications of the three welded-type titanium condenser units which have been completed. The following is a description of the investigation, particularly concentrating on the development the planning of welded-type titanium condensers for power plant.

Investigation of Tube-to-tubesheet Joints

In planning titanium condensers, the decision on whether tube-to-tubesheet joints should be produced by tube expansion of welding was the item of investigation given priority over decisions on all other specifications. It is obvious that welded joints are far superior to rolled joints from the standpoint of joint strength and airtightness. However, rolled joints are advantageous from the standpoint of manufacturing ease and economy. In the initial planning stage, the
following items were considered as basic problems to be solved upon adopting welded joints.

(1) Whether it would be possible to weld tens of thousands of titanium tubes at a power plant construction site without posing problems as to the quality of welding as well as meeting the deadline date of work completion.

(2) When titanium tubes are to be welded to tubesheets, it is necessary that the tubesheets also be of titanium material—namely, titanium plate or titanium-clad plate. Would it be possible to produce large-sized titanium plates to meet this requirement?

Item (2) was readily solved, since the material manufacturer rather quickly succeeded in establishing a technique for manufacturing large-sized plates. As a result of careful study, it was concluded that item (1) was possible. The technique of on-site welding titanium tubes is the main point discussed in this paper.

Study of Tube and Tubesheet Specifications

To cope with ammonia attacks on air cooling zones, a comparatively large amount of titanium tubes was first used approximately 12 years ago as condenser tubes for fossil power plants. In Japan, thin-walled welded tubes have been used since then, resulting in no leakage. Thus, the welded-type titanium condenser also employs thin-walled welded tubes rather than seamless tubes. Regarding tube wall thickness, the 0.5mm value is applied. This value has been determined as a result of study on coping with ammonia attacks on air cooling zones. The 0.3mm value shows weakness in the strength aspect, while the 0.7mm value suggests difficulty regarding cost. Thus, the 0.5mm value has been selected (in Table I, 0.7mm wall thickness is applied only to the outer rows of the tube arrangement for the 600MW fossil power plant. Although 0.5mm is considered to be sufficient from the design standpoint, 0.7mm has been applied at the user's request.).

Regarding the diameter and length of tubes, no restrictions other than those imposed on conventional brass tubes are imposed on the design and manufacture of tubes.

Titanium solid plate is applied to the tubesheet in this instance. The dimensions are listed in Table I. We assume that titanium-clad steel plate will replace titanium solid plate in the future, mainly, because of the latter's high cost.

Study of Tube and Tubesheet Strength

It is an actual fact that having thin-walls, titanium tubes are slightly inferior to brass tubes in strength. On titanium condensers, therefore, it is necessary to precisely know the strength of each part. Based on the recognition that adequate strength of the tube and tubesheet is one of the essential factors to be confirmed in designing titanium condensers, we quite some time previously began vigorous research on stress analysis, eventually completing the study in 1971. As a result of the stress analysis research, it was revealed that the careful measures should be taken to cope with heavy tensile loads acting on the tubes on the outer rows of the tube arrangement when pressure from the circulating pump while it is shut off is applied to the condenser tubes. It was proved that welded tube-to-tubesheet joints (rather than rolled joints) are desirable to cope with the tensile loads. This is one of the primary reasons for adopting welded tube-to-tubesheet joints. Validity of the calculation has been proved by the measurement using a strain gauge of the stress acting on tubes during test runs of the condenser in the 600MW fossil power plant.
Examination of Hydrogen Absorption

Titanium is phenomenally resistant to corrosion and erosion by seawater—that is, deposit attacks; inlet attacks, and sand erosion. Its only demerit is that it absorbs hydrogen and becomes brittle in environment of high temperature and high hydrogen concentration. In fossil power plants, hydrogen absorption of titanium tubes in air-cooling zones caused by cathodic protection system has posed a problem. This was solved by properly setting the cathodic polarized potential. Titanium condensers are free from this problem, since condensers of this type require no cathodic protection system. In BWR plants, hydrogen absorption on tube exteriors, caused by hydrogen gas in steam, was another matter of concern. As a result of hydrogen analysis on titanium tubes which were experimentally put into service in BWR plant condenser for 15,900-hour operation, no increase was observed in the amount of hydrogen. Thus, it was confirmed that the titanium tubes absorbed no hydrogen from steam.

Study of Tube Vibration

Although tube vibration is not a problem peculiar to titanium tubes, the thin walls of this type of tube makes it imperative that the phenomenon be thoroughly examined. The span of support plates was determined according to the following standards:

1. To prevent adjacent tubes from contacting each other, tube deflection caused by the force of turbine exhaust flow shall be held within the limit.

2. No resonance shall occur between the tube natural frequency and the rotations of the turbine generator.

Regarding titanium condensers, span of support plates is less than that for brass-tube condensers.

Study of Tube Cleanliness Factor and Average Circulating Water Velocity Within Tubes

Unlike copper-alloy tubes, titanium tubes are free from the requirement concerning protective film maintenance. Titanium tubes can fully utilize a sponge-rubber-ball tube cleaning system. While it may be possible to assume a value close to 100% as a design cleanliness factor, we consider that for the time being the factor should be determined by mutual agreement between the user and the maker.

It may be possible to reduce condenser cost by decreasing the condenser surface or the quantity of titanium tubes to be used as a result of increasing the average circulating water velocity in tubes. On the other hand, both increased circulating pump cost and power consumption result. Thus, it doesn't necessarily follow that the overall cost is reduced. While the average circulating water velocity in tubes is determined according to the result of cost comparison, it is known that the optimum velocity is presently in the vicinity of 2.3m/s.

Protection against Bio-fouling

Although data concerning titanium-tube bio-fouling is insufficient, it has been reported that tubes of this type cannot be expected to produce the protective effects against bio-fouling that are produced by copper-alloy tubes.

While pouring chlorine in seawater has been adopted as effective protection against bio-fouling, this practice was recently forbidden from the standpoint of pollution. Thus, sponge-rubber-ball tube cleaning systems and backwashing systems have become mandatory accessories to titanium condensers, which replace chlorine
pouring as protection against bio-fouling. In this planning stage of titanium condensers, various tests and examinations were conducted to achieve effective operation of a sponge-rubber-ball tube cleaning system and a backwashing system. As a result, it was disclosed that the following items are important to attain effective operation of the systems:

1. It is desirable to operate a sponge-rubber-ball tube cleaning system once a day. The period of ball circulation per cycle is recommended to be 30 minutes to one hour.

2. The condenser waterbox should be designed so that neither stagnation nor vortex is caused to prevent marine life from attaching to the waterbox, and to prevent the sponge rubber balls from stagnating within the waterbox. The shape of the waterbox was determined based on the result of model tests.

3. It is desirable to reverse the seawater flow in the condenser every 24 hours. It has been determined from experience that the attachment of marine life (such as barnacles) is dominant in the high-temperature interiors of tubes on the seawater outlet side. Seawater flow reversed daily, causing changes in the temperature, is remarkably effective in preventing barnacles from clinging to the waterbox.

Welding Operation and Quality Control in the Field

Reliability of a welded-type titanium condenser finally depends on the quality control system intended to keep the field welding environment under favorable conditions, to immediately detect defects, if any, and to adopt necessary corrective measures. Further, it is essential that the operators (including welders) be thoroughly trained.

The following is a description on welding operations and quality control in the field.

Welding Environment

To maintain the welding environment under favorable conditions, it is necessary to consider measures against wind, dust and moisture, and to provide ventilation. Further, it is necessary to take measures for air-conditioning in the case of a 1100MW nuclear power plant condenser, since welding operation will be performed over a considerably long period. As a protective measure against wind and dust, the condenser water chamber and tubesheets were kept in a cubicle covered by windbreaker sheets. Fresh air was constantly fed into the cubicle by a blower. To prevent dew from condensing on the tubesheet surfaces, a heater or dehumidifier was installed on the blower outlet side to protect against dust and moisture, and to ensure ventilation. Especially, ventilation was essential to prevent oxygen exhaustion possibly caused by argon gas used as shielding gas for TIG arc welding and by cleansing agents used to clean the tube ends and tube holes. A constant check was made on the instrument for recording oxygen concentration within the cubicle.

Preparations for Welding

Sound edge preparation is essential to achieve a satisfactory weld zone. Titanium tubes were inserted in the condenser shell in accordance with the optimum method and procedure of inserting tubes, with attention paid to protecting the tube ends. A visual inspection was conducted on tube ends and tube holes before and after inserting the tubes in the tube holes to confirm that grooves for welding the tube-to-tubesheet joints remained sound after inserting the tubes in the tube holes.
Titanium tubes and tubesheets were thoroughly cleaned prior to shipping from the factory to the field. However, it was unavoidable that they would suffer subsequent fouling to some extent. Since cleaning the grooves is the essential key to eliminating weld defects, emphasis was placed on instructions that the tube ends and tube holes should be thoroughly cleaned immediately before welding. That is, cleaning should be limited to the number of places to be welded for a particular day's operations. Regarding the cleaning agent, before selecting one type of agent, its cleaning effect, poisonous effect on human beings, flammability, effect on the rubber lining inside the waterbox, and ease of operation were investigated.

During and after cleaning operation, special work clothes and shoes were used in waterbox to constantly keep the waterbox interior clean.

Welding Operation

To weld more than 200,000 tube-to-tubesheet joints, automatic welding must be employed from the standpoint of quality control. All welding operations in the field were performed by small-scaled, lightweight, high-performance welding equipment developed by Toshiba. Welding was conducted by welders selected from those qualified to perform normal TIG arc welding operations, and who further passed the qualification test for welding titanium tube-to-titanium tubesheet joints.

Fig. 1 shows a welding operation being conducted in the field. Each welder was obliged to confirm the soundness of his welding operation by checking the color of the surface of weld beads. Most failures in welding titanium materials are caused through fouling by the atmosphere. The extent of atmospheric fouling can be precisely judged by the welding bead color. Generally, when fully shielded from the atmosphere, beads show a metallic silver white, a sight of satisfactory welding. Naturally, internal defects—including blow holes—cannot be detected visually. However, in the case of a weld with a silver-white appearance, there is little probability of internal defects. When oily matter in the vicinity of grooves is not completely removed, or when atmospheric fouling is caused by improper shielding, welds show various colors from light yellow to yellow, blue, and violet. In an extreme case, the weld is coated with a powder.

Toshiba established a welding operation procedure that included repair welding, and all welding operations were executed according to this procedure. Considering the capacity of the welder, amount of welds per welder per day was determined approximately 90 places to obtain required quality. This number of welding spots corresponded to about two hours of continuous welding operation.

For the 600MW fossil power plant condenser, all welding operations (30,176 spots) were completed in 45 days.

Inspection of a Weld Zone

To achieve a sound weld, operations related to welding must be smoothly performed according to pertinent regulations. A visual inspection was conducted on the entire lot of tube ends and tube holes at each sequential operation from inserting titanium tubes in tube holes, cleaning, expanding, cutting tube ends, and welding. Results were recorded on the condition of each tube end and tube hole. This formed a system which made it possible to retrace the history of defective weld zones—if any.

Repetitive inspections at each operation facilitates the detection of defects, preventing defective work from being carried over to any further operations.

To check a weld zone for soundness, a liquid penetrant examination, vacuum leak test, and water tightness test by filling with water were conducted. We established its liquid penetrant examination procedure after confirming the capability of this test to detect a defective weld by the result of the liquid penetrant test.
on a weld of a model condenser. We also developed special jigs for the vacuum leak test designed to prove the vacuum and the capability of this test to detect possible leakage. Fig. 2 shows the welding bead on the power plant condenser. The tightness test by filling water, a conventional leak testing procedure applied to condensers, was adopted as an already proved procedure. All inspectors and supervisors engaged in these inspections were required to pass a qualification test for inspection of titanium welds, the same as required of welders. Defects on welds detected by inspection amounted to approximately 0.02%. These were mainly attributed to the welding machines (weld zones were fouled by the atmosphere caused by incomplete gas shielding). These defective weld zones were repaired by rewelding after cutting off the defective portions. Since defects of this type can be prevented by improving the welding machines, we are convinced that trouble involving weld zones will be reduced to zero during welding operations in a subsequent plant project. As already mentioned, all welding operations for tube-to-tubesheet joints were conducted with special automatic welding machines under Toshiba's meticulous quality control system, resulting in perfectly satisfactory results.

**Results of Operations**

The completed welding-typed titanium condensers represent a "world's first" achievement in this field. Five months has elapsed since the test run of the condenser for the 600MW fossil power plant. During operation under 100% load, it has been confirmed that the condenser displayed performance conforming to the design value. Taking the opportunity of the outage of the plant, we entered the waterbox to inspect the weld zones and confirmed no defects noticeable on the weld zones. The sponge-rubber-ball tube cleaning system was operated once a day, while forward washing and backwashing were alternately repeated every 24 hours. This resulted the tubesheet surface and tube interior had been kept very clean. The condenser is designed to prevent decreased performance during backwashing. While the plant was at a standstill, we entered the condenser body to inspect the tube exteriors. As a result of careful observation on tube exteriors close to the steam drain inlet on the boiler starting system, no abnormal conditions were apparent.

**Conclusion**

When the cost of titanium material and man-hours consumed in tube welding are taken into account, a welded-type titanium condenser is more expensive rather than conventional aluminum brass tubed condenser. However, in considering the electricity loss caused by reducing the load to install blind plugs during possible leakage from tubes on a brass tube condenser, we estimate that the high cost of the welded-type titanium condenser can be offset by the possible loss of several cases of leakage from the Al brass tubes. Further, as for a nuclear power plant, when the exposure of maintenance personnel to radiation is considered, a welded-type titanium condenser has further merit. We anticipate that this type of condenser will be widely employed. In addition to the three units just completed, Toshiba has received orders for another three new welded-type titanium condensers--two units for a 1100MW nuclear power plant and one unit for a 600MW fossil power plant. The design and manufacture of these condensers are under way. We sincerely hope that this paper will suggest to readers new approaches and procedures for installing welded-type titanium condensers under the circumstances mentioned herein.
Table I Specification of Titanium-Tubed Condenser with Welded Tube-to-Tubesheet Joint

<table>
<thead>
<tr>
<th>Name of Power Plant</th>
<th>Tokyo Electric Power Co. Hirono Thermal P/S No.1 &amp; No.2</th>
<th>Tokyo Electric Power Co. 2nd Fukushima Nuclear Power Station No.1</th>
</tr>
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<tr>
<td>Commercial Operation</td>
<td>April 1980 (No.1) July 1980 (No.2)</td>
<td>May 1982</td>
</tr>
<tr>
<td>Tube OD x Wall Thick.</td>
<td>1⅛ in x 0.0197 in 0.0276 in (*)</td>
<td>1 in x 0.0197 in</td>
</tr>
<tr>
<td>Number</td>
<td>15,088</td>
<td>72,648</td>
</tr>
<tr>
<td>Material</td>
<td>JIS H4631 TTH35W (ASTM B338 Gr2 equi.)</td>
<td>JIS H4631 TTH35W (ASTM B338 Gr2 equi.)</td>
</tr>
<tr>
<td>Tube Width x Height</td>
<td>13 ft 9 in x 15 ft 4 in</td>
<td>10 ft 10 in x 23 ft</td>
</tr>
<tr>
<td>Material</td>
<td>JIS H4600 TP49 H (ASTM B265 Gr3 equi.)</td>
<td>JIS H4600 TP49 H (ASTM B265 Gr3 equi.)</td>
</tr>
<tr>
<td>Waterbox Corrosion Protection</td>
<td>Rubber Lining</td>
<td>Rubber Lining</td>
</tr>
<tr>
<td>Cathodic Protection System</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Tube Cleaning System</td>
<td>Sponge - Rubber - Ball</td>
<td>Sponge - Rubber - Ball</td>
</tr>
<tr>
<td>Chlorine Pouring Device</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Backwashing System</td>
<td>4-way Valve System</td>
<td>4-way Valve System</td>
</tr>
</tbody>
</table>

(*1) Applicable to only three rows on tube arrangement
Fig. 1  Welding operation in the field

Fig. 2  Welding bead on the nuclear power plant condenser