EXPERIENCE WITH TITANIUM TUBED CONDENSERS

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The universally acknowledged high corrosion resistance of titanium in sea water has lead to an increasing number of steam condensers in thermal power plants being fitted with titanium tubes in recent years. While the high corrosion resistance of titanium is beyond doubt, the other materials used in the condenser and the design have to be adapted to the stability of titanium.

Compared with copper alloys, titanium has a much lower failure rate, as shown in, table 1:

Table 1: Corrosion resistance of titanium compared to copper alloys

Type of attack	Titanium	CuZn20Al	CuNi30Fe
Sulfide-oxygen attack	-	X	X
Erosion corrosion at tube inlet	-	X	X
Erosion corrosion at obstacle in tube middle	-	X	X
Ammonia-induced SCC in humid air	-	X	X
Steam impingement	X	X	X
Vibration	X	X	X

X Attacks possible

In well designed condenser necks and tube bundles steam impingement, which is due to the impact of water droplets on the condenser tubes, is minimal. The resistance of titanium tubes to droplet impingement attack under simulated condenser operating conditions has been investigated by BBC. Titanium has an erosion resistance which is much higher than that of copper alloys and almost equal to that of stainless steel.

Vibration is controlled by correctly spacing the tube support plates. Due to the smaller number of different failure mechanisms it is obvious that titanium tubes will show a higher reliability and need less care and maintenance. This is reflected in the failure rate FR which is lower for titanium tubes in BBC condensers than for Al-Brass (CuZn 20Al).

$$FR = \frac{\%\ \text{perforated tubes}}{\text{service hours} \times 10^4}$$

Table 2: Failure rates of different tube materials

Material	FR
Titanium in seawater	<0.0001 to 0.001
CuZn20Al in seawater (during the first 2 years)	≤0.005
CuNi30Fe in seawater (during the first 2 years)	≤0.005

The mean time between failures (MTBF, in 10^4 hours) of the condenser tubes will depend on the FR and the number of tubes:

$$MTBF = \frac{100}{FR \cdot n}$$

Consequently a big unit with a higher number of tubes will probably show a higher number of affected tubes which had to be plugged.

While the titanium tubes are very resistant to corrosive attacks, the other parts of the condenser, such as tubesheets and waterboxes have to be adapted to match the high quality of titanium.

Table 3: Tubesheet materials and fixing procedures

tube sheet	fixing
solid titanium	welding or roller expansion
titanium-clad mild steel	welding or roller expansion
316Ti-clad mild steel	roller expansion
copper alloy	roller expansion

With titanium or titanium clad mild steel tubesheets, it is possible to either weld or roller expand the tubes. If old tube sheets of stainless steel (AISITP 316Ti or W.Nr. 1.4571) clad mild steel or copper alloys are used when retubing a condenser, roller expansion is always possible.
The following questions will be discussed: Tightness of roller-expanded joints, welding, fabrication and crevice corrosion resistance of stainless steels.

Tightness of roller expanded tube to tubesheets joints
In order to make the expanding technique safe for thin walled condenser tubes of titanium, extensive tests were carried out and the results have been applied in many condensers.

Investigation of rust blistering in some condensers showed that the surface of the tube holes after drilling must fulfil certain requirements. Cleanliness requirements during tubing is important for a tight expansion joint.

Expanding tests were conducted with two different roller expanding methods using tilted rollers and axially parallel rollers (1). Titanium tubes were expanded into test tubesheets of carbon-steel boiler plate with stainless steel cladding (Fig. 1).

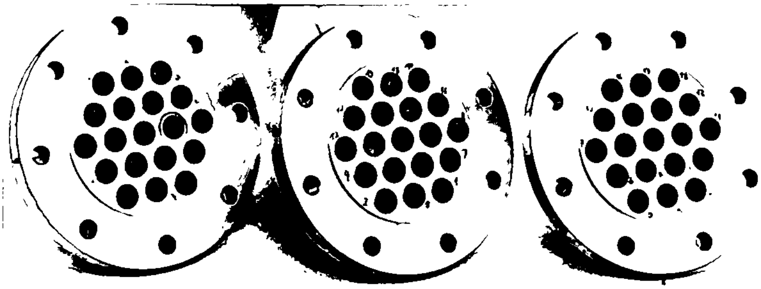


Figure 1: Test Tubesheets

Leakage tests were made with helium. The results are given in Fig. 2. With the expanding method using inclined rollers the measured leakage rates lie within a relatively wide range between 10^{-5} and $< 10^{-9}$ (mbar . l/sec), whereas expandings with axial-parallel rollers show a relatively small variation range between 5.10^{-7} and $< 10^{-9}$ (mbar . l/sec).

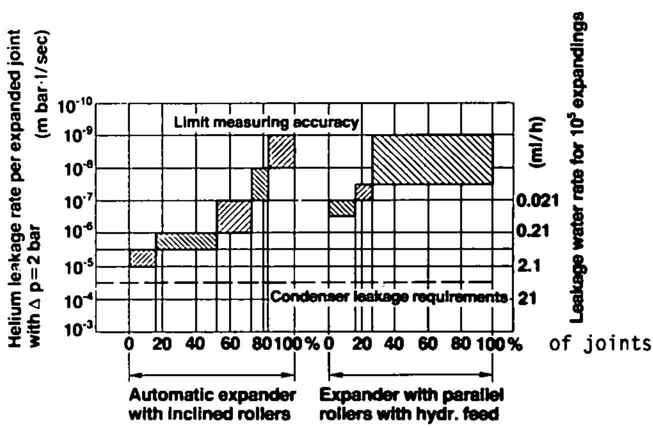


Figure 2: Leakage rate distribution with different expanding techniques

The tightness requirement for a large condenser of a 1000 MW nuclear power plant with 50 000 tubes and 100 000 expanded joints nowadays is < 10 ml/h for a permissible total leakage rate for water. This corresponds to a mean helium leakage rate per expanded joint of 5.10^{-5} (mbar . l/sec) with 2 bar pressure difference, based on water vapour penetration and corresponds to the worst case. According to the test results for the expansion technique with inclined rollers the max. leakage rate is approx. 10^{-5} (mbar . l/sec). If all expanded joints were to indicate this leakage rate the total water leakage rate would be 2.1 ml/h. As the mean leakage rate, however, is considerably lower (acc. Fig. 2 less than 0.2 ml/h) a condenser of this type can be stated to be adequately tight. In contrast to this the max. leakage rate when expanding with axial-parallel rollers is approx. 5.10^{-7} (mbar . l/sec). Even if all the expanded joints were to indicate this leakage rate the total water leakage rate would be only 0.1 ml/h, with an available safety factor of 100 as against the specified requirements. A condenser expanded in this way can be stated to be absolutely tight. (Mean leakage rate acc. Fig. 2 less than 0.002 ml/h). Also pullout tests have shown that in all specimens the fracture was in the tubes and not in the tube-to-tubesheet joint.

Welded tube-to-tubesheet joints

Since the welding of titanium in general and the welding of thin wall titanium tubes to tubesheets in particular place high requirements on manufacturing technology, BBC has thoroughly investigated these aspects.

The tubes are roller expanded into the tubesheets and welded to the face of the tubesheet. While the weld assures complete tightness, the tube stresses are accommodated by the expanded joint and thereby kept away from the welds.

Numerous weld test specimens have been examined in the laboratory.

Leakage tests after static and dynamic loading up to 10000 cycles showed a leakage rate for all specimens which was less than 10^{-9} (mbar . l/sec).

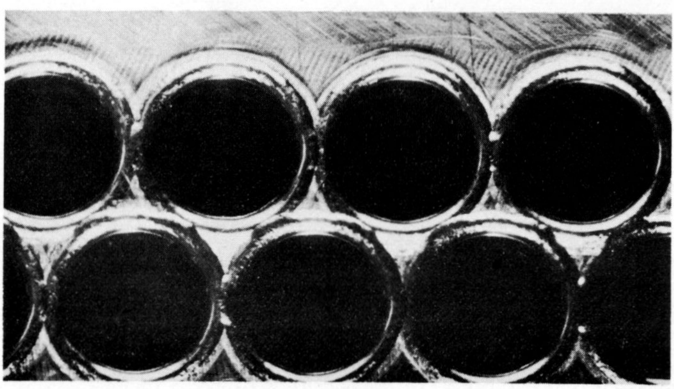


Figure 3: Welded tube-to-tubesheet joints

All the above mentioned tests resulted in special instructions being issued for fabrication, tubing and welding. BBC and its licencees have already fabricated welded condensers and other heat exchangers with excellent results (Fig. 3).

Whereas the advantages of the expanded joint are to be found in its application under difficult erection site conditions and in retubing existing condensers the weld joint offers itself for new condensers and for retrofitting with prefabricated condenser modules.

When retubing existing condensers with titanium tubes, fixed by expanded joints, the existing tubesheets can be reused in most cases thus reducing the outage time considerably.

Prefabricated condenser modules

Condenser retrofitting with prefabricated and shop tubed modules of the BBC church-window type offers the following advantages (2):

- ease of fabrication
- improved tightness
- increased output due to higher thermal performance
- no subcooling in the hotwell
- very low O_2 concentration
- short outage time

The condenser modules are prefabricated in the workshop and transported to site for installation in the existing condenser shell (Fig. 4). The modules consist mainly of tube bundles, tubesheets, support plates, side walls, air coolers and stay tubes. The number of tube bundles per module depends on the transport and installation facilities available.

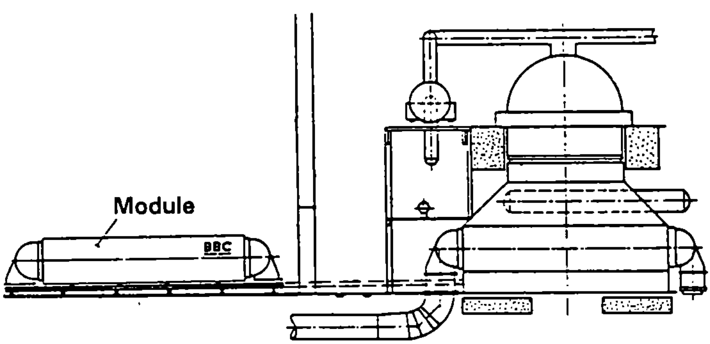


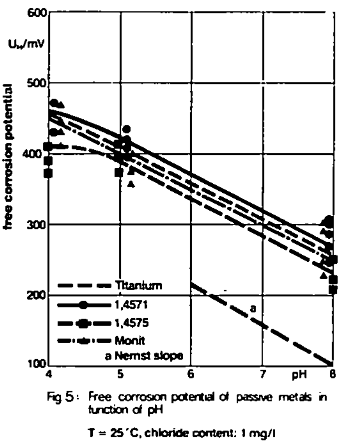
Figure 4: Prefabricated Condenser Modules

Crevice corrosion resistance of stainless steels

If titanium tubes are fitted in tubesheets of copper alloys, the latter must be protected from galvanic attack by a cathodic corrosion protection system.

Tubesheets and other parts made of stainless steels may suffer from crevice corrosion, and investigations have been made to judge the susceptibility of different stainless steels against this type of attack.

In crevice corrosion a preformed crevice filled with stagnant electrolyte is in contact with a large cathodic surface. In condensers the cathodic surface not only comprises the stainless steel tubesheet, but also the titanium tube surface. In the absence of anodic surface the cathodes would reach their free corrosion potential which is shown for different materials in Fig. 5, Table 4.
The diagram also shows that the free corrosion potential of passive metals is a strong function of the pH of the electrolyte. In fact in the pH-region of 4-8 the specimens behaved similar to pH-electrodes.



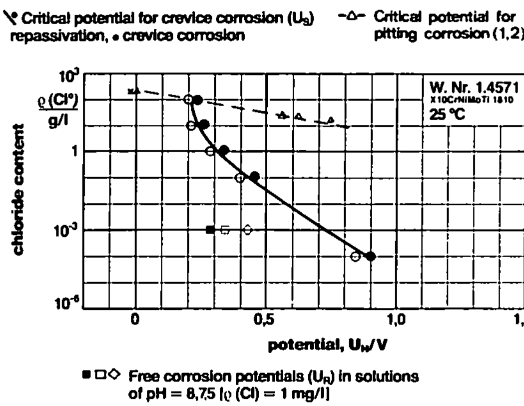


Figure 5: Free corrosion potential of passive metals

Figure 6: Chloride-Potential Diagramm of 1.4571

The behaviour of 1.4571 Ti under crevice corrosion conditions has been described elsewhere (5, 6) [Fig. 6]. The chloride-potential diagram above indicates the critical potential U(s) for crevice corrosion, which is also the repassivation potential of actively corroding crevices.
As the diagram shows there is a region to the left of U(s), where no crevice corrosion takes place and actively corroding crevices would passivate.
As the free corrosion potential of 1.4571 and titanium lies in the region of crevice corrosion at chloride concentrations higher than 1 g/l, attack can only be avoided by reducing the potential of the free surface by an appropriate cathodic protection.
BBC condensers are therefore protected with sacrificial anodes in the waterbox. This system is very reliable and less expensive than impressed current systems (Fig. 7).On the left in the picture a reference electrode and a potential meter can be seen. With this device it is possible to measure the mixed potential in the waterbox during service. The high efficiency of the cathodic corrosion protection system can therefore be monitored continously.

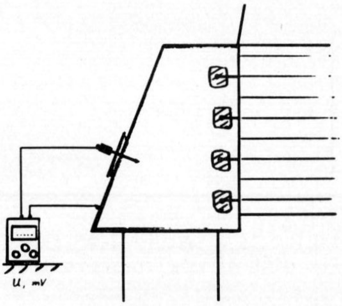


Figure 7: Cathodic corrosion protection

In addition to protecting the tubesheets cathodically it is also possible to seal the tube/tubesheet joints with an acrylic polymer. The absence of all crevices can easily be demonstrated by a dye check test.

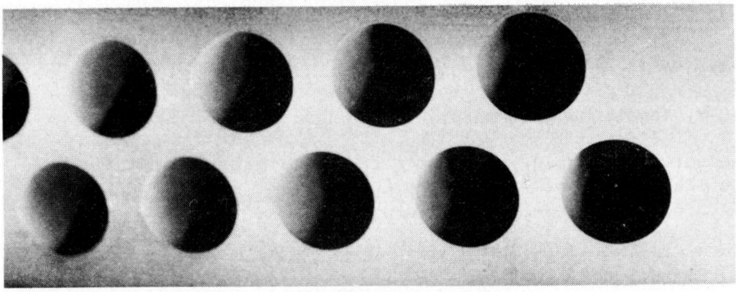


Figure 8: Dyecheck of sealed tube joints

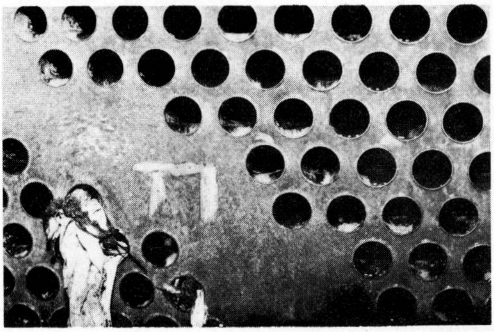


Figure 9: Titanium tubes rolled into 316-clad mild steel

No corrosion problems caused by fouling

Table 4: DIN-Number of stainless steels

DIN-No	Name	
1-4571	X10CrNiMoTi	1810
1-4575	X1CrNiMoNb	2842
Monit	X2CrNiMo	2544

For seawater cooled heat exchanger tubes titanium is a material of the future and BBC has been obtaining good results with it now for more than twelve years.

References

(1) H. Eberle: Requirements and experience with mechanically expanded tube joints, EPRI symposium on state-of-the-art condenser technology, June 1983, Orlando Florida.

(2) H.V. Lang: "Church-window" condenser concept, design and experience, EPRI symposium on state-of-the-art condenser technology, June 1983, Orlando Florida.

(3) Z. Szklarska.Smialowska, J. Mankowski, Corr. Sci. 18, (1978), 953-960

(4) T. Suzuki, M. Yamabe, Y. Kitamuro, Corr. NACE 291 (1973) 18-22

(5) R. Scheidegger, R.O. Müller, Loch- und Spaltkorrosion von Chrom- und Chromnickelstählen in chloridhaltigen Lösungen, Werkst. u. Korr., 31 (1980) 387-393.

(6) R.O. Müller, Crevice Corrosion Test for Stainless Steels in Chloride Solutions, Fifth Internat. Symposium on Passivity, Extended Abstracts, Soc. de Chimie Physique, Bombannes, France, (1983), 136-138.