Alloy 194 – Superior Performance and Lower Cost Versus Admiralty Brass (Alloy 443)

Admiralty Brass tube (Alloy 443) has been widely used in condenser and heat exchanger applications due to its good corrosion resistance in fresh water, good biofouling resistance, and excellent heat transfer characteristics. A lesser-known and lower cost alternative to Alloy 443 is Alloy 194, which is a high strength modified copper. In fresh water applications, Alloy 194 provides better performance than Alloy 443 in important functional requirements such as corrosion resistance, biofouling resistance, and heat transfer. Due to its greater corrosion resistance and higher modulus of elasticity, Alloy 194 tube can be used at a reduced wall thickness which results in its cost advantage.

Composition

The chemical composition of Alloys 194 & 443, as defined in ASTM B-543, are shown in Table 1 below. Alloy 194 is a high copper alloy that is alloyed with iron and deoxidized with phosphorus. The resulting microstructure contains finely dispersed iron and iron phosphide precipitates that give Alloy 194 its high strength and erosion-corrosion resistance. Alloy 443 is a copper-zinc-tin alloy with an addition of arsenic to inhibit dezincification.

Table 1. Chemical requirements for Alloys 194 & 443 per ASTM B-543.

Alloy	Cu	Pb, max	Fe	Zn	P	Sn	As
C19400	97.0-97.8	0.03	2.1-2.6	0.05-0.20	0.015-0.15	--	--
C44300	70.0-73.0	0.07	0.06 max	Rem.	--	0.8-1.2	0.02-0.06

Water-side Corrosion Considerations

Erosion-corrosion resistance is an important consideration in the water-side performance of condenser tube. Both Alloys 194 & 443 have a generally accepted maximum design velocity of 6 ft/s in fresh water, suggesting very similar performance for the two alloys in terms of erosion-corrosion resistance. However, weight loss studies provide a more direct comparison of the erosion-corrosion characteristics of different alloys. In one such study, Alloys 194 & 443 were exposed to fresh water flowing at a velocity of 7 ft/s for 360 days. Weight loss measurements were recorded for the alloys at three intervals, and instantaneous corrosion rates were calculated at these intervals. As shown in Table 2 and Figure 1, Alloy 194 experienced less weight loss and had a lower instantaneous corrosion rate, thus indicating superior erosion-corrosion resistance as compared to Alloy 443.

Table 2. Results of weight loss study in which Alloys 194 & 443 were subjected to fresh water at a velocity of 7 ft/s. Alloy 194 experienced less weight loss, which indicates its higher resistance to erosion-corrosion as compared to Alloy 443.

Alloy	Weight Loss, mg/cm^2			Corrosion Rate, mg/cm^2/day		
	60 days	180 days	360 days	60 days	180 days	360 days
C19400	2.75	5.42	6.90	0.031	0.015	0.0037
C44300	3.81	7.58	9.98	0.050	0.021	0.0067

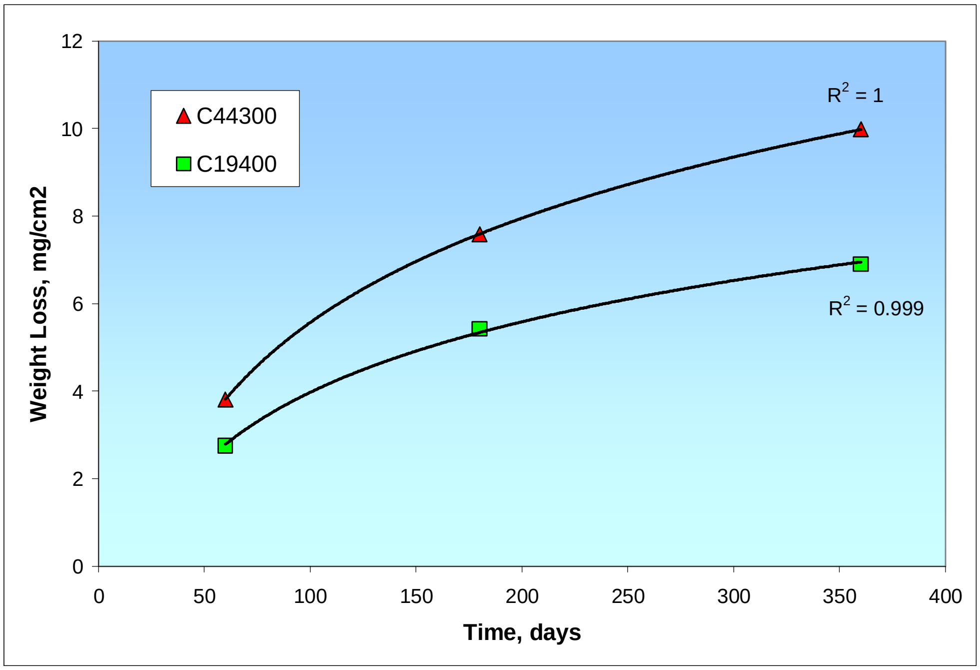

Figure 1. Weight loss versus time curves for Alloys 194 & 443 exposed to fresh water at a velocity of 7 ft/s.

Steam-side Corrosion Considerations

While condenser tube failures typically are not caused by steam-side corrosion, three possible steam-side failure mechanisms exist. They are increased general corrosion rates, stress corrosion cracking, and steam impingement erosion.

The general corrosion rate of copper alloys can be increased by ammonia in the presence of oxygen. Ammonia treatments are often used in power generation plants to adjust the pH of the feedwater. In the main body of the condenser, ammonia and oxygen concentrations are typically low enough that problems do not arise. The service conditions in the air removal section are somewhat more severe and ammonia attack is more of a concern.

In one weight loss study, the resistance of Alloys 194 & 443 and several copper-nickel alloys to ammonia attack was investigated. In the study, the alloys were exposed to 1000 ppm NH_3 contaminated condensate at 100^{o} F for 10 days. As shown in Figure 2, Alloy 194 experienced less weight loss than Alloy 443, thus indicating its superior resistance to ammonia attack. The copper-nickel alloys are shown to be essentially immune to ammonia attack under these conditions. For this reason, copper-nickel alloys are frequently specified for the air removal section of a condenser.

Stress corrosion cracking can occur in condenser tube due to the combination of residual stresses (e.g., from rolling-in to the tubesheet) and the presence of ammonia. Alloy 443, due to its high zinc content, is susceptible to this type of failure. By contrast, Alloy 194 is essentially immune to stress corrosion cracking.

Regarding steam impingement resistance, no comparative data are available; however, based on its higher resistance to erosion-corrosion and ammonia attack, Alloy 194 should exhibit a higher resistance to steam impingement than Alloy 443.

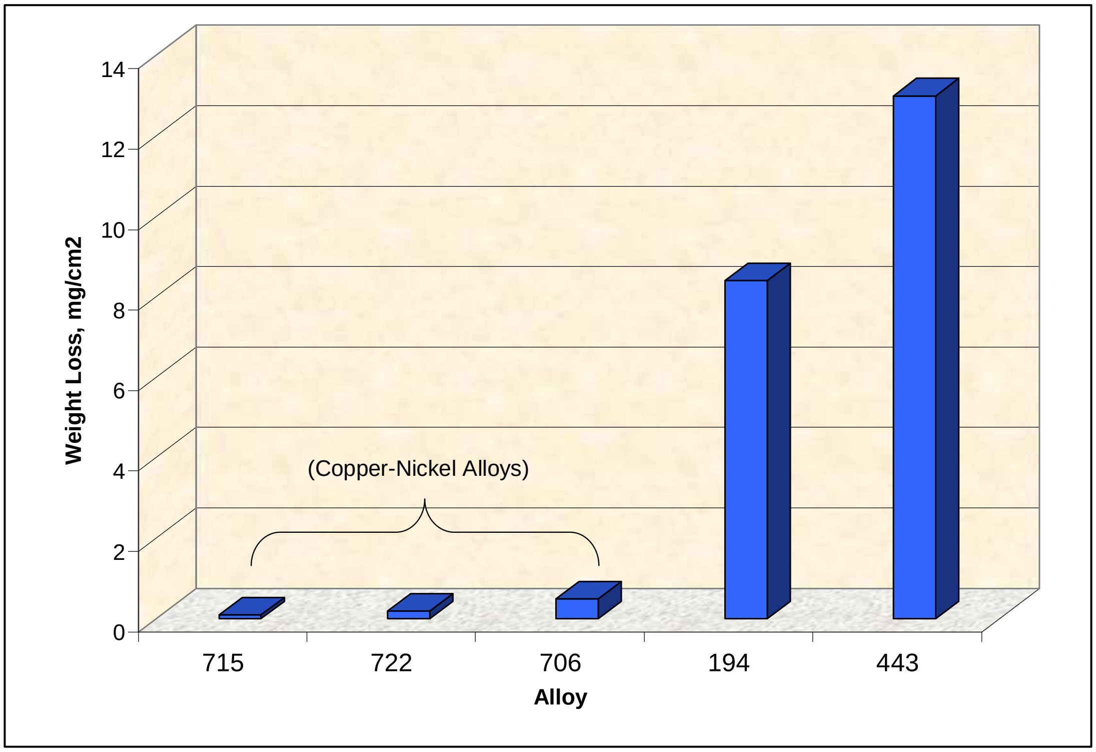

Figure 2. Weight loss versus time curves for Alloys 194 & 443 and several copper-nickel alloys exposed to 1000 ppm NH_3 contaminated condensate at 100^o F for 10 days.

Biofouling

Marine organisms attach themselves to some metals and alloys more readily than they do to others. Biofouling reduces heat transfer and can contribute to crevice corrosion at attachment sites. All copper-based alloys have excellent resistance to biofouling. Due to its higher copper content, Alloy 194 will have slightly better biofouling resistance than Alloy 443.

Heat Transfer Characteristics

Since Alloy 443 has been widely used at .049" wall thickness (18 BWG) in condenser applications and has excellent heat transfer characteristics, it is considered the standard to be used for comparing condenser tube materials. Consequently, the Heat Exchange Institute (HEI) has assigned a gauge correction factor of 1.00 for Alloy 443 at .049" wall thickness as shown in Table 3 below. Alloy 194 has even better heat transfer characteristics than Alloy 443 as evidenced by its higher thermal conductivity and gauge correction factor. In addition, due to its improved corrosion resistance in many applications, Alloy 194 can be specified at a reduced wall thickness (.042" wall or 19 BWG) which provides further improvement in heat transfer ability while providing a cost savings.

Table 3. Thermal conductivity and gauge correction factors for Alloys 194 & 443 as listed in the Heat Exchange Institute's "Standards for Steam Surface Condensers" (Ninth Edition).

Alloy	Thermal Conductivity*	HEI Gauge Correction Factor @ .049" wall
C19400	150	1.03
C44300	64	1.00

** BTU·ft/ft^2·hr·^{0}F (@ 68^{0}F)*

Wall Thickness Considerations

As previously discussed, the superior corrosion resistance of Alloy 194 as compared to Alloy 443 allows the use of Alloy 194 at a reduced wall thickness. For a given material, a reduction in wall thickness will increase tube vibration and deflection that can lead to tube fretting and mid-span collision. However, as shown below, Alloy 194's higher modulus of elasticity allows it to be used at .042" wall (19 BWG) in place of .049" wall (18 BWG) Alloy 443 without these concerns.

The following is a formula from "The Design and Manufacture of Large Surface Condensers – Problems and Solutions" by Coit, Peake, and Lohmeier (Westinghouse Heat Transfer Division) which was published in the 1966 Proceedings of the American Power Conference. L_c is the maximum allowable tube span for a given alloy, diameter, and wall thickness as a function of service conditions.

$$L_c = 21.8 \{S_c E I \delta / \rho V^2 D\}^{1/4}$$

where:
- S_c = Severity Factor (conservative value = 1.7, 2.0 = acceptable)
- ρ = Steam Density (lbs/ft^3)
- V = Average Steam Velocity @ Inlet (ft/sec)
- D = Tube Diameter (in.)
- δ = Logarithmic Decrement of Vibrating Tube
- E = Material Modulus of Elasticity (psi)
- I = Cross Sectional Moment of Inertia (in.)

To consider an alternate material, such as Alloy 194 in place of Alloy 443, the L_c values can be set equal to each other. Since the tube diameter and service conditions are the same, the only variables remaining after simplification are the modulus of elasticity and the wall thickness. Since the modulii of elasticity are known (Alloy 443 = 16.0×10^6 psi & Alloy 194 = 17.5×10^6 psi), the minimum required wall thickness for the alternate material (Alloy 194) to be equivalent to the original material (Alloy 443) can be calculated.

Using this calculation for a 1.00" x .049" wall (18 BWG) Alloy 443 tube, the minimum wall thickness required for Alloy 194 is determined to be 0.0402". Thus, it is shown that Alloy 194 tube at .042" wall can be used with the same support plate spacing as Alloy 443 tube at .049" wall without any concern for mid-span collision.

Cost Comparison

Using actual pricing, cost indices for Alloys 194 & 443 were prepared and are shown below in Table 4.

Table 4. Cost indices for Alloy 194 & Alloy 443 condenser tube at .042" and .049" average wall thickness, respectively.

Tube Item	Cost Index
1" x .049" x Alloy 443	1.00
1" x .042" x Alloy 194	*0.95*

Service Experience

Dating back to 1969, Olin Fineweld Tube has supplied over 22 million feet of Alloy 194 condenser tube to power generation plants, with much of it still in service today. The following is a list of Alloy 194 condenser tube purchases through December 2009:

UTILITY	PLANT	WALL (IN)	ALLOY	FEET (000)	DATE
Louisiana Power & Light (Entergy)	Sterlington 6	0.035	194	34	Apr-69
Delmarva Power & Light	Vienna	0.035	194	24	Jun-69
Tennessee Valley Authority	Watts Bar	0.035	194	178	Jun-70
Carolina Power & Light	Lee 1	0.035	194	267	Apr-71
Wisconsin Power & Light	Blackhawk	0.049	194	24	Jul-71
Allegheny Power (W. Penn)	Armstrong 2	0.035	194	214	Apr-72
Ohio Power Co. (AEP)	Amos 3	0.042	194	3,361	Jun-72
West Texas Utilities	Fort Phantom 1	0.035	194	9	Aug-72
Cincinnati Gas & Electric	Miami Fort 7	0.049	194	988	Sep-72
Ohio Power Co. (AEP)	Gavin 1	0.042	194	3,361	Sep-72
Louisville Gas & Electric	Mill Creek 2	0.042	194	619	Jan-73
Ohio Power Company (AEP)	Gavin 2	0.042	194	3,361	Jan-74
Buckeye Power Inc. (AEP)	Cardinal 3	0.042	194	1,617	Sep-74
Cincinnati Gas & Electric	Zimmer 1 (N-BWR)	0.049	194	2,032	Apr-75
Cincinnati Gas & Electric	Miami Fort 8	0.049	194	907	May-75
Louisville Gas & Electric	Mill Creek 3	0.042	194	860	Jun-75
Kentucky Utilities	Ghent 2	0.049	194	973	Aug-75
Cincinnati Gas & Electric	East Bend 2	0.049	194	1,201	Oct-78
Indiana-Kentucky (AEP)	Kyger Creek 1	0.049	194	450	Jun-86
Cinergy Corp.	Miami Fort 8	0.049	194	455	Aug-01
Ohio Power (AEP)	Kammer 1	0.042	194	450	Mar-05
Sierra Pacific Power Co.	Tracy 3	0.049	194	192	Aug-05
Central Power & Lime	Brooksville 1	0.042	194	288	Oct-05
Detroit Edison	Conner's Creek 16	0.042	194	216	Mar-06
Detroit Edison	River Rouge 2	0.042	194	593	Apr-06
Duke - Kentucky	East Bend 2	0.049	194	610	Feb-07
SWEPCO (AEP)	Lieberman 3	0.049	194	255	Apr-07
Detroit Edison	Conner's Creek 15	0.042	194	314	Feb-08
Detroit Edison	Trenton Channel 7A	0.042	194	291	Dec-08
Duke - Ohio	Miami Fort 7	0.049	194	973	Mar-09
Kentucky Utilities	Ghent 1	0.049	194	1,038	Dec-09

Conclusion

Alloy 194 is a lower cost alternative to Admiralty Brass (Alloy 443) for condenser tube applications. In addition to the "lower cost" benefit, the end user also benefits from Alloy 194's higher heat transfer capability and superior corrosion resistance. For these reasons, Alloy 194 is an excellent candidate for condenser maintenance retubings.