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Fineweld® Tube — TECHNICAL LETTER

Alloy C194 vs. Alloy C122 for Air Conditioning and Refrigeration Applications

Connection tube is an important element in a refrigeration/air conditioning system transmitting fluids between major system components – the compressor, condenser, and evaporator. Typical applications of connection tube include headers, manifolds, and liquid and suction lines. This tube is generally larger in diameter than the heat transfer tubing used in the condenser and evaporator. Large rooftop units, for example, may use tube as large as 3 in. (76 mm) in diameter.

Copper is the conventional connection tube material, and alloy C122, a phosphorus deoxidized grade, is most commonly specified. It has generally been considered to be invulnerable to material substitution because its combination of joinability, field repairability, fabricability, strength, and corrosion resistance could not be matched by other metals.

Alloy C194, an iron-modified phosphorus deoxidized copper represents a viable alternative to alloy C122. Its high strength, resistance to softening during brazing, and superior corrosion resistance permits tube wall reductions of nearly one-third relative to C122, with resultant cost savings. The following discussion illustrates how alloy C194 can provide equal or better performance versus alloy C122 with regard to mechanical properties, corrosion resistance, and fabrication/installation, while reducing overall cost. Although heat transfer capability is generally not an important requirement for connection tube applications, a brief discussion on heat transfer is included for those readers that might be interested.

Mechanical Properties

Connection tube must be strong enough to withstand operating pressures over a wide range of temperatures and be able to resist fatigue failure due to vibration and cyclic loading. As shown in the following table [1], alloy C194 has superior tensile, yield, and fatigue strengths when compared to alloy C122.

Table 1 – Selected Properties of Alloys C194 & C122

Chemical Compositions per ASTM B-543, %	Alloy C194	Alloy C122
Copper	97.0-97.8	99.90 min
Iron	2.1-2.6	- - -
Zinc	0.05-0.20	- - -
Phosphorus	0.015-0.15	0.015-0.04
Mechanical & Physical Properties		
Density, lbs/cubic inch	0.322	0.323
Specific gravity	8.92	8.94
Coefficient of thermal expansion, 10^{-6} in/°F	9.7	9.8
Modulus of elasticity, psi	17,500,000	17,000,000
Tensile Strength, min, psi		
Hard temper	60,000	36,000
Soft temper	45,000	30,000
Yield Strength, min, psi		
Hard temper	52,000	29,000
Soft temper	15,000	9,000
Elongation, % in 2 in		
Hard temper	5	8
Soft temper	30	45
Fatigue Strength, 10^3 psi @ 10^8 cycles	16-20	11-14

The superior strength of alloy C194 is the key to its cost advantage; its higher strength allows tube wall reductions of approximately one third relative to the wall thicknesses commonly used for Alloy C122 without decreasing the burst pressure or the safe working pressure below that which is available from tubes made of alloy C122.

Burst pressure [2] is calculated using the formula P = (2St)/D where:

P = burst pressure, psi
S = minimum soft temper tensile strength, psi
t = wall thickness, inches
D = outside diameter, inches.

Using this formula, the burst pressures for some common Type L Alloy C122 connection tube sizes can be compared with those for Alloy C194 tubes at wall thickness reductions of approximately one-third. From table 1, the minimum soft temper tensile strength for C194 is 45,000 psi, and it is 30,000 psi for C122. The results are shown in Table 2.

Table 2 – Burst Pressure Comparisons of Reduced Wall Alloy C194 vs. Type L C122

Nominal OD, in.	Actual OD, in.	Wall Thickness, in.		Burst Pressure, psi	
		Alloy C194	Alloy C122	Alloy C194	Alloy C122
½	0.625	0.027	0.040	3,888	3,840
5/8	0.750	0.028	0.042	3,360	3,360
¾	0.875	0.030	0.045	3,086	3,086
1	1.125	0.033	0.050	2,640	2,667
1-1/2	1.625	0.040	0.060	2,215	2,215

Even at a wall thickness which is one-third less than C122, the burst pressures of alloy C194 tubes are equal to or better than those of alloy C122 tubes.

The safe working pressure [2] for tubes can be calculated using the following formula given in the ASME Code for pressure piping (ASME B31):

$P = (2S(t_{min}-C)) / (D_{max}-0.8(t_{min}-C))$ where:

P = safe working pressure, psi
S = maximum allowable stress in tension, psi
t_{min} = minimum wall thickness, inches
D_{max} = maximum outside diameter, inches
C = a constant

For copper tube, because of its good corrosion resistance, the B31 code permits the factor C to be zero. The formula thus becomes:

$P = 2St_{min} / (D_{max}-0.8t_{min})$

The value of S in the formula is the maximum allowable stress for continuous long-term service of a tube material, and the value depends upon the service temperature and the temper of the tube. It is only a small fraction of a material's ultimate tensile strength or burst strength. Allowable stress values for alloys C122 and C194 [3] in the annealed temper from Table 502.3.1 of ASME B31.5 are shown below in Table 3.

Table 3 - Allowable Stress Values for Annealed Temper Alloy C122 and Alloy C194 at Various Temperatures

Temperature	Allowable Stress, psi	
	Alloy C122	Alloy C194
100F	6000	8500
150F	5100	8400
200F	4900	8300
250F	4800	8100
300F	4700	7800
350F	4000	7600
400F	3000	6000

In Table 4, the safe working pressure at 150°F for some common Type L alloy C122 tube sizes are compared with those of alloy C194 tubes at wall thickness reductions of approximately one-third. The values used for the maximum diameter and minimum thickness used for these calculations were based on the wall thickness and diameter tolerances listed in ASTM B-251 [4].

Table 4 – Safe Working Pressures for Reduced Wall Alloy C194 vs. Type L C122

Nominal OD, in.	Actual OD, in.	Wall Thickness, in		Safe Working Pressure, psi	
		Alloy 194	Alloy 122	Alloy 194	Alloy 122
½	0.625	0.027	0.040	683	632
5/8	0.750	0.028	0.042	585	544
¾	0.875	0.030	0.045	540	501
1	1.125	0.033	0.050	457	435
1-1/2	1.625	0.040	0.060	384	361

As can be seen, the "safe working pressures" for alloy C194 are greater than those for alloy C122, even at a wall thickness for C194 which is one-third less than the C122.

Corrosion Resistance

Corrosion resistance is also an important requirement for connection tube and, in this regard, the corrosion resisting properties of alloy C194 are superior [5] to those of alloy C122. This is because the corrosion product film developed on alloy C194 is considerably different from that formed on copper. Cuprous oxide, Cu_2O, forms on both C122 and C194 in an aqueous environment. However, as a result of the small addition of iron in C194, the compound lepidocrosite (γ Fe.OH) is developed in the corrosion product film of C194. Since lepidocrosite is an excellent cathodic inhibitor, C194 is protected by a "built-in" inhibitor treatment similar to that provided by the addition of ferrous sulfate to cooling waters.

In laboratory tests conducted at the Olin Metals Research Laboratories, the steady state corrosion rate of both alloys C122 and C194 was evaluated in two different waters – New Haven tap water and a 3.4% sodium chloride solution. New Haven tap water is a relatively soft water, slightly acidic, and with a generally high level of dissolved carbon dioxide and oxygen; it is therefore considered to be an aggressive water. The 3.4% NaCl solution was intended to simulate seawater service. Testing was conducted in flowing water – 7 fps for the New Haven tap water and 5 fps for the simulated seawater. As illustrated in the weight loss versus time curves, figures 1 and 2, the results for both potable water and brine, demonstrate the superiority of Alloy C194 versus C122. Note that the instantaneous steady state corrosion rate, i.e. the tangent to the weight loss versus time curve at 360 days, is approaching zero for the alloy C194. These tests were conducted under conditions considered to be more aggressive than would likely be experienced in normal service. However, the results may be representative of long term service in extremely aggressive environments. Equally important, these data provide a means of evaluating erosion-corrosion resistance, a failure mode often experienced in applications where sharp bends, constrictions, joints, etc. are present. The C194 is clearly the superior alloy.

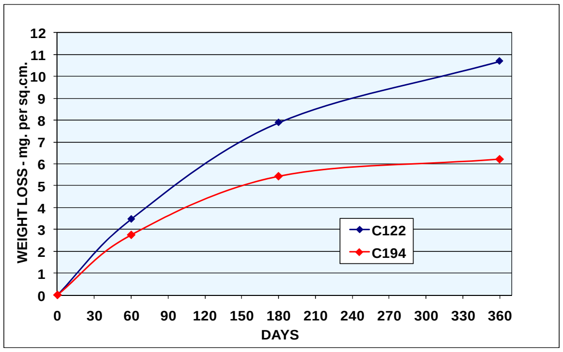

Figure 1 – Corrosion of Alloys C194 and C122 in New Haven Potable Water at 7fps.

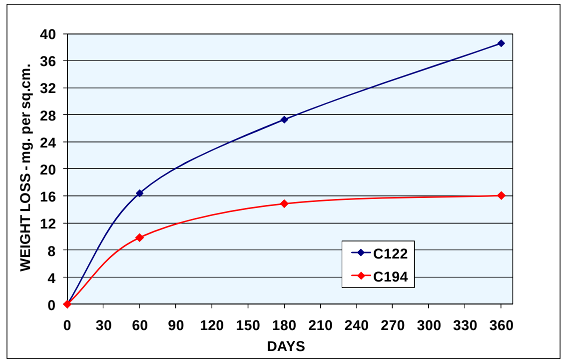

Figure 2 – Corrosion of Alloys C194 and C122 in a 3.4% NaCl solution at 5 fps.

As a further testimony to the superior corrosion resistance of alloy C194, it is has found widespread use as a condenser tube material in power plant steam surface condensers, an application which is too corrosive for alloy C122.

Finally, alloy C194, like C122, is not susceptible to stress corrosion cracking, nor hydrogen embrittlement at elevated temperatures.

Heat Transfer Capability

The thermal conductivity of C194 is 150 Btu's/sq.ft./ft./hr./°F versus a thermal conductivity for C122 of 196 Btu's/sq.ft./ft./hr./°F. Despite this difference, there is very little difference in the heat transfer capability of the two alloys and, in systems where Freon is one of the fluids, the heat transfer capability of the two alloys is essentially the same. This is because the heat transfer resistance of the fluid films and the protective oxide films that form on the ID and OD of the tubes as well as other types of fouling such as crystalline fouling (scaling) and biological fouling all contribute more to heat transfer resistance than does the tube wall. This will be illustrated in the following paragraphs.

For heat transfer in a tubular heat exchanger where heat is transferred from a warmer fluid to a cooler fluid through a solid wall, the heat flow is expressed as:

$$Q = U\,A\,\Delta T$$

where:
Q = Heat flow rate - Btu's per hour
U = Overall heat transfer coefficient – Btu's/ hr.-°F-sq.ft.
A = Effective heat transfer surface area – square feet
ΔT = the overall difference between the bulk temperatures of the two fluids (the logarithmic mean temperature difference (LMTD) of the two fluids should be used in heat exchangers where the local temperature difference ΔT varies along the flow paths).

In the equation above, the overall heat transfer coefficient is defined [6] as:

$$U = \frac{1}{\frac{1}{h_o} + r_o + \frac{d_o \ln(d_o / d_i)}{24k} + \frac{r_i d_o}{d_i} + \frac{d_o}{h_i d_i}}$$

where:

U = Overall heat transfer coefficient – Btu's/ hr.-°F-sq.ft.
h_o = Heat transfer coefficient for the fluid on the OD of the tube – Btu's/ hr.-°F-sq.ft.
h_i = Heat transfer coefficient for the fluid on the ID of the tube – Btu's/ hr.-°F-sq.ft.
r_o = Fouling resistance on the OD of the tube – hr.-°F-sq.ft./Btu
r_i = Fouling resistance on the ID of the tube – hr.-°F-sq.ft./Btu
k = Thermal conductivity of the tube material – Btu-ft/ sq.ft-hr.-°F
d_o = Outside diameter of the tube - inches
d_i = Inside diameter of the tube - inches

The values of the fluid heat transfer coefficients (h_o and h_i) to be used in this equation depend upon the physical properties and flow velocities of the fluids, and the geometry of the system. The values of the fouling factors (r_o and r_i) to be used in this equation also depend upon the physical properties and flow velocities of the fluids, but also upon the purity, or cleanliness, of the fluids. Values for both the heat transfer coefficients and fouling resistances can be determined from experience, but when such data is not readily available, data from industry references can be used.

For example, from the ASHRAE Handbooks [7], we can get a value of 1365 Btu's/ hr.-°F-sq.ft. for the heat transfer coefficient h_i for cooling water flowing inside a tube at 7 fps at 80°F. From the TEMA Standards [6], we can get values for the ID and OD fouling resistances of 0.001 and 0.0005, respectively.

Finally, from various research publications, a value of 200 Btu's/ hr.-°F-sq.ft. appears to be a reasonable assumption for the heat transfer coefficient h_i for Freon in two phase condensation.

Inserting these values into the equation for the overall heat transfer coefficient, for various diameters and wall thicknesses, shows that the heat transfer capability of C194 at a one-third wall reduction is 0.03% greater than C122; and at an equivalent wall thickness, the heat transfer capability of C194 is 99.9% of that for C122. These calculations have been borne out in a blind field test where samples of both alloys were tested; the result was that C194 was indistinguishable from C122.

Fabrication/Installation

Connection tube materials must be suitable for joining (e.g. brazing or soldering) and for fabrication (e.g. bending, spinning, drilling, extruding, piercing, or swaging). As discussed in the following paragraphs, alloy C194 is equal to or better than alloy C122.

Joining

The most common method of joining copper tube is by soldering with 50-50 tin-lead solder, or 95-5 tin-antimony solder. The techniques for soldering alloy C194 are exactly the same as those used for C122; nothing need be changed

Where greater strength is required, or where service temperatures approach 350°F, brazed joints with capillary fittings are preferred. Alloy 194 is readily brazeable to itself, copper, and other materials such as steel and brass using exactly the same techniques and filler metals conventionally used for copper [8] including brazing alloys BCuP2, BCuP3, BCuP4, BCuP5, BAg1, BAg2, BAg5, and BAg7.

The retention of strength after brazing is also an important consideration for headers and manifolds where multiple brazing operations may result in prolonged exposure to high temperatures. In this regard, alloy C194 is superior to alloy C122. The microstructure of alloy C194 contains finely dispersed iron and iron phosphide precipitates which inhibit grain growth during brazing operations.

As shown below in Table 5, alloy C194 is much stronger than alloy C122 after brazing and does not experience measurable grain growth.

Table 5 – Strength of Alloys C194 & C122 After Brazing

Tube Material	Brazing Temperature	Strength, psi		Grain Size, mm
		Tensile	Yield	
Alloy C194	500°C	50,000	25,000	0.010
	800°C	41,000	16,000	0.010
Alloy C122	500°C	33,500	7,000	0.022
	800°C	31,000	5,000	0.035

Note: Results based on 1 hour exposure at temperature

These characteristics mean that brazed alloy C194 components will have higher strength in areas adjacent to the joint. There will also be a greater tolerance for variations in the brazing operation with no major concern for grain growth. These features lend further support for the use of reduced-wall alloy C194 tube.

Fabrication

Reduced-wall alloy C194 tubes can be readily bent, without wrinkling, when appropriate ball mandrels are used to handle the larger inside diameter. With very tight radii, the use of a wiper die may be helpful in making a smooth bend. Based on actual experience, only minor modifications to equipment tooled for working copper are needed when switching to reduced-wall alloy C194.

Conclusion

In the past, alloy C122 has often been the only material considered for connection tube in air conditioning/refrigeration applications. However, alloy C194 tube represents a viable alternative. It has higher strength, higher fatigue strength, better resistance to softening during brazing, and better corrosion resistance versus alloy C122. As a result, alloy C194 tube when used at a reduced wall thickness will deliver equal or better performance versus alloy C122 tube, and at a lower "per piece" cost.

Bibliography

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