CAST COPPER-BASE ALLOYS FOR DESALINATION PLANTS

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Summary

Copper base alloys used in desalination plants fall into three main classes: the brasses, the bronzes and the cupro-nickels. They are obtained as wrought or cast products. The advantages and drawbacks of casting copper alloys are briefly given. Because of their thicker cross-section, more freedom to modify the melt composition and possibility of post-heat treatment, cast products usually exhibit better corrosion performance compared to their wrought analogs.

Tin-bronzes are produced only as castings. The designation and composition of available cast tin-bronzes and leaded tin-bronzes are listed.Aluminum-bronzes are a family of copper alloys containing aluminum, iron and nickel. They are pseudo-bronzes as they contain no tin. They have outstanding resistance to corrosion in a marine environment.

The designation and composition of cast copper-nickel alloys, with iron and manganese additions, are given. The widely used alloys are the nominal 90:10 and 70:30 Cu-Ni, which have excellent corrosion resistance to general-, localized- and erosion-corrosion. They are also immune to SCC even at high temperatures.With each class of alloys the effects of added minor element on the metallurgical and corrosion behaviors are described in short. Problems encountered during melting and casting are also listed.

1. Introduction

Because of its noble character, copper exhibits good resistance to atmospheric as well as aqueous corrosion. In practice the metal is not chosen for that ability alone, but rather for that characteristic plus one or more other property (Layman 1978). Usually the high thermal conductivity of the element is the overriding factor; and copper is considered to be an ideal material for heat exchangers operating on fresh-, brackish- and sea-waters.

Pure copper lacks, however, the necessary mechanical strength. Accordingly, it is either cold-worked or alloyed with other metals. As little as a few tenths of one weight per cent of elements like Ag, As, P, Te, Fe, Pb, etc. are enough to affect the mechanical properties of copper without noticeably altering its physical characteristics. A large family of such alloys, with copper contents ≥ 99.3 per cent, is known and its members are referred to as the coppers. They corrode in seawater evenly and slowly, but suffer severe erosion-corrosion at water flow rates exceeding ca. $1\ m\ s^{-1}$. On the other hand, alloys with copper contents ≥ 96 per cent for wrought- and ≥ 94 per cent for cast material are designated as "high copper" alloys. Likewise, these are seldom used in marine environment or in seawater desalination plants. For this purpose alloys with still lower copper contents are employed. Three classes of alloys of industrial application are known. These are:

(a) The brasses: these contain zinc as the principal alloying element.

The bronzes: originally the term referred to alloys containing tin as the only or principal alloying element. Nowadays the name bronze also describes tin-free copper alloys in which the major alloying element is neither zinc nor nickel.

For the non-specialist there exists some confusion between the brasses and the bronzes. Both simple brasses and simple bronzes have useful properties lacked by the others. In an effort to improve on the characteristics of both classes of materials, zinc was added to bronzes and tin was added to brasses, with the result it became difficult to decide what an alloy should be called. Confusion is further increased by coining the name "bronze" to some low-alloy brasses, just to praise their properties. Because of the aura of excellence attached to the word "bronze", there is nowadays on the market a number of bronzes which are not bronzes and do not have the general characteristics of bronzes. Examples are the manganese bronzes, the aluminum bronzes and the silicon bronzes, which are in fact high tensile brasses. The term "pseudo-bronzes" has been suggested to describe this group of brasses (Shams El Din 1993).

Brasses and bronzes are further subdivided into sub-classes or families. There are three main wrought- and four main cast alloy families of brasses. Bronzes, on the other hand, comprise four main wrought- and four main cast families of alloys (Copper Development Association).

The cupro-nickels: The two elements copper and nickel are freely soluble in one another and form a single phase solid solution. A large number of cupro-nickel alloys have been prepared, but only few have gained technical importance.
Other copper-alloy systems are the "copper-nickel-zinc alloys", commonly known as "nickel silvers"; the "leaded-coppers" with 20 per cent or more lead; and "special alloys", whose compositions do not fall into any of the above categories (Copper Development Association). With the exception of leaded-coppers, which are produced only as cast alloys, all copper alloy systems are available as wrought and as cast

products. The objective of this article is to highlight cast copper-base alloys used in desalination plants and to describe their corrosion characteristics in seawater.

2. Advantages and Drawbacks of Castings

Metals and alloys may be obtained as wrought or cast products. Wrought products are subjected to rolling and forming operations. This requires alloy compositions with reduced strength and noticeable hot and cold working ductility.

Practically for every wrought alloy composition a corresponding grade in casting can be obtained. However, because cast products require little or no mechanical working, the composition of the cast grades can be more freely modified relative to their wrought equivalents. This allows unique and improved properties to be imparted to castings. For this reason, and as a result of design freedom associated with casting techniques, some alloys are available only as castings. The alloy composition and the shape of the produced article determine the casting process to be used. The manufacturer has to decide between pressure die-casting, sand-, continuous-, permanent mould- or centrifugal casting.

Casting offers the highly appreciated advantages of manufacturing complex components, of minimizing machining and material waste, and of rationalizing production costs. Casting of alloys has, however, its own design and operation problems. For example, molten copper, and to a lesser extent its alloys, have the tendency to dissolve both oxygen and hydrogen. Upon solidification, the two gases can combine to form water vapor which induces porosity of the product. Hydrogen alone produces the same effect. On the other hand, alloys containing aluminum form oxide skins which give rise to unsound castings. Special melting and treatment techniques, comprising fluxing, degassing and deoxidation treatments, are employed to overcome these effects. Other limitations of casting are: material quality which may vary from one casting to the other as well as from one foundry to the other, surface finish of inside areas; internal integrity and compositional homogeneity (Schweitzer 1989). Most of these drawbacks are either reduced or eliminated through the application of stringent and rigorous measures.

The corrosion behaviour of cast copper alloys has been less studied compared to that of the wrought counterparts. One would expect the two to be similar. Better performance of castings is, however, frequently experienced. There are a number of reasons behind this observation. Cast products have a longer life as a result of their thicker cross sections. Also, the extra freedom of modifying the composition of the melt through additions of beneficial minor elements in many cases improves the corrosion resistance of the cast. Finally, the application of appropriate heat treatment helps in relieving residual stresses, the break-down of undesirable metallurgical phases and/or inhibiting dealloying processes.

On the other hand, improper melting and casting can lead to easily corroding cast products. This occurs when degassing, oxide-occlusion and metal segregation are not adequately treated.

3. Designation of Copper Alloys

The original system for designating copper alloys, due to the U.S. copper and brass industry, had three digits. It has now been extended to five digits, following a prefix letter C (Copper Development Association). For example, forging brass originally designated as Alloy 377, is now referred to as C 37700.

Further, numbers from C 10000 through C 79999 denote wrought alloys. Numbers C 80000 through C 99999, on the other hand, are reserved for cast alloys. The designation of the various classes and sub-classes (families) of cast copper alloys are shown in Table 1 (Schweitzer 1989).

System	Unified numbering system	Description	Major constituents
Coppers	C 80100-C 81100		Cu
High coppers	C 81300-C 82800		Cu, Cr, Be, Co, Ni, Si
Brasses	C 83300-C 83800	Red brasses, leaded red brasses	Cu, Zn, Sn, Pb
	C 84200-C 84800	Semi-red brasses, leaded semi-red brasses	Cu, Zn, Sn, Pb
	C 85200-C 85800	Yellow brasses, leaded yellow brasses	Cu, Zn, Sn, Pb
	C 86100-C 86800	Manganese bronzes, leaded manganese bronzes	Cu, Zn, Al, Mn, Pb
	C 87200-C 87900	Silicon bronzes and brasses	Cu, Zn, Si
Bronzes	C 90200-C 91700	Tin bronzes	Cu, Sn
	C 92200-C 92900	Leaded tin bronzes	Cu, Sn, Pb
	C 93200-C 94500	High-leaded tin bronzes	Cu, Sn, Pb
	C 94700-C 94900	Nickel-tin bronzes	Cu, Sn, Ni
	C 95200-C 95800	Aluminum bronzes	Cu, Al, Fe, Ni
Copper-nickels	C 96200-C 96600		Cu, Ni, Fe, Mn
Nickel-silvers	C 97300-C 97800		Cu, Ni, Zn
Leaded coppers	C 98200-C 98800		Cu, Pb.
Special alloys	C 99300-C 99700		Cu, Ni, Fe, Al. Zn.

Table 1. Classes and families of cast copper alloys (Schweitzer 1989).

Of these various systems only four find application in structures operating on seawater. These are the tin-bronzes (C 90200-C 91700), the leaded tin-bronzes (C 92200-C 92900), the aluminum bronzes (C 95200-C 95800) and the copper-nickels (C 96200-C 96600).

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Bibliography and Suggestions for further study

A. Múñoz Elguera, S.O. Pérez Báez (2005),Development of the most adequate pre-treatment for high capacity seawater desalination plants with open intake ,Desalination, Volume 184, Issues 1-3, Pages 173-183

A.M.Shams El Din(1993),Copper alloys for desalination plants ,Desalination Volume 93, Issues 1-3, Pages 499-516

Anderson D B (1981) *NACE corrosion 81*, paper 197, Toronto.

Anees U Malik and P.C. Mayan Kutty(1992), Corrosion And Material Selection In Desalination Plants,SWCC 0 & M Seminar, Al Jubail.

B. Todd (1967),The corrosion of materials in desalination plants ,Desalination, Volume 3, Issue 1, Pages 106-117

Bog S (1975) *7th Scand. Corrosion Congress*, Trondheim.

Breckon C and Baines J R T (1955) *Institute of Marine Engineers Transactions* 67(10), 1.

Copper Development Association, Standard designation for wrought and cast copper and copper alloys. New York: Copper Development Association Inc.

Foseco Foundryman's Handbook (1994) 10th ed., section V, *Copper and Copper Alloy Castings*. Butterworth, Heinemann.

Ghiazza E. and Peluffo P.(2003), A new design approach to reduce to reduce water cost in MSF evaporators. Proc. IDA world congress on desalination and water reuse, Bahamas .

K. Habib, A. Fakhral-Deen (2001),Risk assessment and evaluation of materials commonly used in desalination plants subjected to pollution impact of the oil spill and oil fires in marine environment ,Desalination, Volume 139, Issues 1-3, Pages 249-253

Layman W and Cohen A (1978) *Chemical Engineering* 85(6), 99.

Maetsch R E and Cieslewicz J M (1974) *Materials Prot.* 3(7).

Olsson J. and Falkland ML.(2000), The Versatility of Duplex. Proc. Stainless Steel America 2000, Stainless Steel World, Houston 2000.

Olsson J. and Liljas M.(1994), 60 years of duplex stainless steel applications. Proc. NACE Corrosion ’94, Baltimore .

Olsson J. and Minnich K.(1999), Solid stainless steel for MSF once through plants. Proc. Desalination and water reuse, EDS, Las Palmas.

Rogers T H (1968) *Marine Corrosion*. London: George Newnes.

Schweitzer P A (1989) *Corrosion and Corrosion Protection Handbook*. New York: Marcel Dekker.

Shams El Din A M (1993) *Desalination* 93, 487, 499.

Simon P D (1983) *NACE corrosion 83*, paper 77, Anaheim.

Sommariva C., Pinciroli D., Tolle E. and Adinolfi R.(1999), Optimization of material selection for evaporative desalination plants in order to achieve the highest cost-benefit ratio. Proc. Desalination and water reuse, EDS, Las Palma.