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by
Brush Wellman Technical Staff

Beryllium copper combines exceptional strength with high electrical and thermal conductivities. By focusing on these attractive properties the corrosion resistance of beryllium copper is sometimes overlooked, when in fact, corrosion resistance prompts its use for many applications.

The manufacturing process for beryllium copper has evolved significantly since the mid-1960's. Advances in ore refinement, melting practice, and in-process quality assurance now provide material that is chemically and physically more consistent. As a result, beryllium copper alloys of today are truly engineered materials, and as such are supported by measurements of corrosion performance.

This paper emphasizes the most recent corrosion data available for these alloys and reviews the corrosion behavior of beryllium copper in a number of common environments. The first and largest section describes the corrosion resistance of beryllium copper in seawater, acids, alkalis and organics. Subsequent sections consider atmospheric corrosion, corrosion by certain gases, galvanic corrosion and stress corrosion cracking. All sections emphasize observed behavior rather than corrosion mechanisms. Two illustrations are cited which highlight the features of beryllium copper for use in seawater and in oil and gas well drilling. Finally, the properties and uses of beryllium copper in corrosive environments are summarized. In general, beryllium copper corrodes at a similar rate to pure copper or high copper alloys. If the corrosion data for beryllium copper in an environment are not available, one may usually assume behavior comparable to copper.

Table 1: Chemical Composition Of Copper Alloys

		Weight Percent							
Copper Number	Description	Cu	Be	Ni	Zn	Fe	Sn	Pb	Other
C17000	Brush Alloy 165	Balance	1.60-1.79	0.20	---	---	---	---	0.6 Co+Ni+Fe
C17200	Brush Alloy 25	Balance	1.80-2.00	0.20	---	---	---	---	0.6 Co+Ni+Fe
C17400	Beryllium Copper	Balance	0.15-0.50	---	---	---	---	---	0.15-0.35 Co
C17410	Beryllium Copper	Balance	0.15-0.50	---	---	---	---	---	0.35-0.60 Co
C17500	Brush Alloy 10	Balance	0.40-0.70	---	---	---	---	---	2.4-2.7 Co
C17510	Brush Alloy 3	Balance	0.20-0.60	1.4-2.2	---	---	---	---	---
C10200	Oxygen Free	99.95	---	---	---	---	---	---	---
C12200	Phosphorous Deoxid.	99.9	---	---	---	---	---	---	0.015-0.040 P
C16500	Cadmium Copper	Balance	---	---	---	0.2	0.50-0.70	---	0.6 -1.0 Cd
C22000	Commercial Bronze	89.0-91.0	---	---	Balance	0.05	---	0.05	---
C23000	Red Brass	84.0-86.0	---	---	Balance	0.05	---	0.05	---
C26000	Cartridge Brass	68.5-71.5	---	---	Balance	0.05	---	0.07	---
C26800	Yellow Brass	64.0-68.5	---	---	Balance	0.05	---	0.15	---
C28000	Muntz Metal	59.0-63.0	---	---	Balance	0.07	---	0.30	---
C44300	Admiralty Brass	70.0-73.0	---	---	Balance	0.6	0.9 - 1.2	0.07	0.02-0.10 As
C46400	Naval Brass	59.0-62.0	---	---	Balance	0.10	0.5 - 1.0	0.20	---
C51000	Phosphor Bronze A	Balance	---	---	0.30	0.10	4.2 - 5.8	0.05	0.03-0.35 P
C51100	Phosphor Bronze	Balance	---	---	0.30	0.10	3.5 - 4.9	0.05	0.03-0.35 P
C52400	Phosphor Bronze D	Balance	---	---	0.20	0.10	9.0 -11.0	0.05	0.03-0.35 P
C60800		Balance	---	---	---	0.10	---	0.10	5.0 -6.5 Al 0.02-0.35 As
C61400		Balance	---	---	0.20	1.5-3.5	---	0.01	6.0 -8.0 Al 1.0Mn/0.015 P
C65500	High Si Bronze A	Balance	---	0.6	1.5	0.8	---	0.05	0.5 -1.3 MN 2.8 -3.8 Si
C70600	Copper-Nickel, 10%	Balance	---	9.0-11.0	1.0	1.0-1.8	---	0.05	1.0 Mn
C71500	Copper-Nickel, 30%	Balance	---	29.0-33.0	1.0	0.4-1.0	---	0.05	1.0 Mn
C72500	Copper-Nickel-Tin	Balance	---	8.5-10.5	0.50	0.6	1.8 - 2.8	0.05	0.20 Mn

Composition percent maximum unless shown as a minimum or range.

Table 1 lists the nominal compositions of the copper alloys included in this review.

Corrosion Resistance

A. Liquid Media

1. Seawater

The corrosion behavior of beryllium copper in seawater has been evaluated and reported by many investigators[1-9]. Richards[1] reported the results of a study conducted at Harbor Island and Kure Beach, NC. Strip specimens of C17200 were exposed to low and moderate velocity seawater in the ocean and tested for effects of high velocity seawater by rotating disk and two jet impingement techniques. Some of the specific results appear in Figures 1, 2 and 3. Low velocity, in this case, means near shore tidal flow of less than 0.6 m/sec (2 ft/sec), while moderate velocity means 0.6 to 1.2 m/sec (2 to 4 ft/sec). At low velocity the corrosion rate decreases slightly with increased exposure time (Figure 1) with nominal values for C17200 of 1 mpy. Figure 2 shows that the metallurgical condition exhibits no effect on the corrosion rate. Under moderate flow conditions, Figure 3, the corrosion rate, again, decreases with exposure time. The increase in flow rate increases the corrosion rate, as shown by comparing the results shown in Figure 1 and 3.

Further increases in the seawater velocity lead to further increases in corrosion. At 4.6 m/sec (15 ft/sec) the protective behavior of corrosion product films on C17200 or pure copper are lost, as measured in a rotating disk apparatus. Three other tests which employed high velocity seawater and entrained air showed that beryllium copper behaved similarly to C12200, phosphorus deoxidized copper, and C44300, arsenical admiralty brass, but not as well as C71500, 70-30 cupronickel.

Figure 4 presents data from a three year program completed in 1978 at the Musashino Electrical Communications Lab in Japan by Tsunoda, Suzuki and Hisamatsu[2]. Beryllium copper C17000 consistently

Corrosion In Seawater

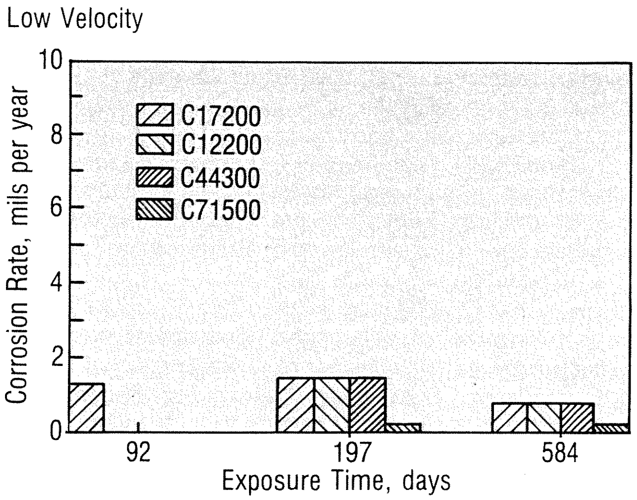

Figure 1- Corrosion of C17200 and three other copper alloys in low velocity seawater as a function of exposure time[1].

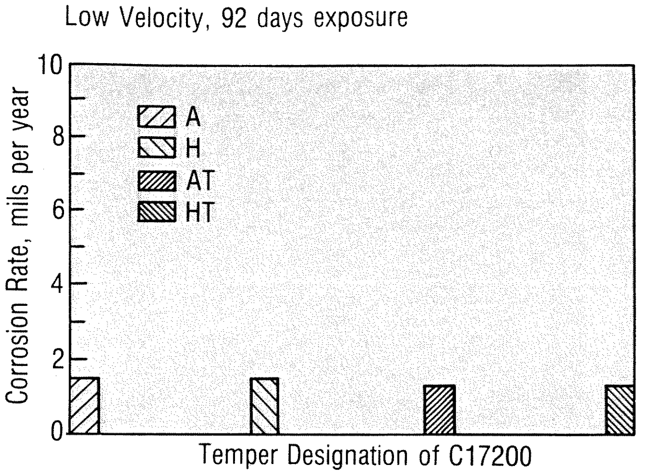

Figure 2- Corrosion of C17200 as a function of temper for exposure in low velocity seawater for 92 days[1].

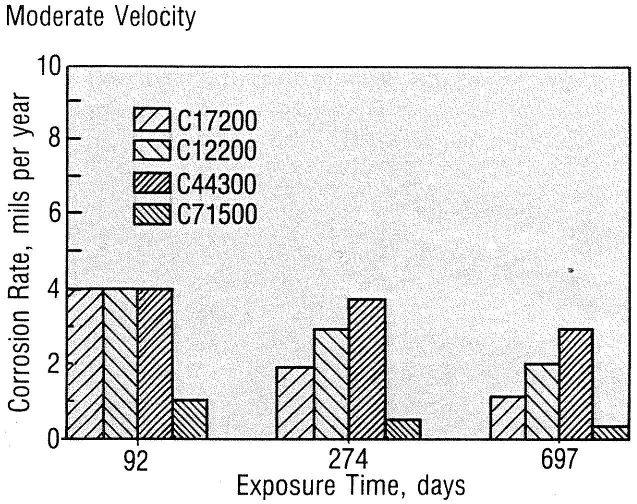

Figure 3- Corrosion of C17200 compared to some other copper alloys in moderate velocity seawater as a function of the exposure time[1].

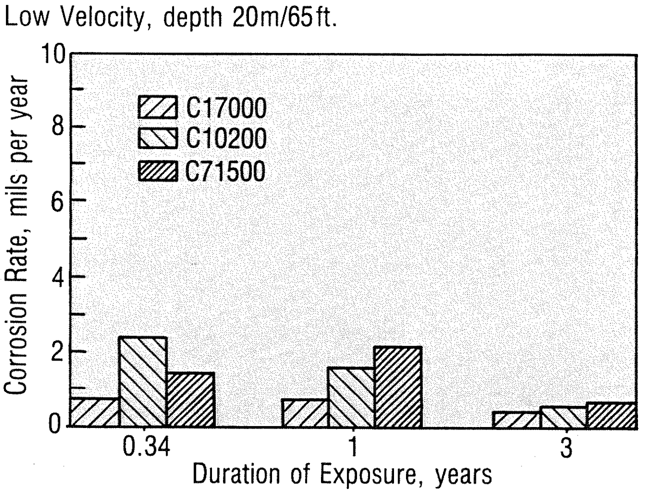

Figure 4 - Corrosion of C17000 compared to some other copper alloys in low velocity seawater at 20 m depth as a function of exposure time[2].

showed about half the depth of corrosion as cupronickel C71500 after exposure at depth of 20 m (65 ft) in seawater for up to one year. After a three year exposure at the same location and depth, the difference was less, but C17000 had a lower rate than C71500. Another experiment was performed over a six month period at the Naval Civil Engineering Laboratory in California in the late 1960's[4]. Beryllium copper C17200 exposed for 6 months in near surface seawater corroded at 0.1 mils per year (mpy) while the cupronickel C71500 rate under the same conditions was about 0.5 mpy. The corrosion rates in static seawater are typically low for beryllium copper (1 mpy or less), however, specific values are not absolute and may change because of local conditions.

Figure 4 also shows that these corrosion rates generally decrease with exposure time as found by Richards[1]. Films from microorganisms and corrosion products develop on the metal surface and impede further attack. Alloys with higher beryllium content offer slightly better corrosion resistance as illustrated in Figure 5[2]. Other results by these investigators show that the degree of cold work and the aging temperature influence the amount of corrosion in artificial seawater[2]. This point may at first seem in conflict with the results of Richards shown in Figure 2, since

Corrosion In Seawater

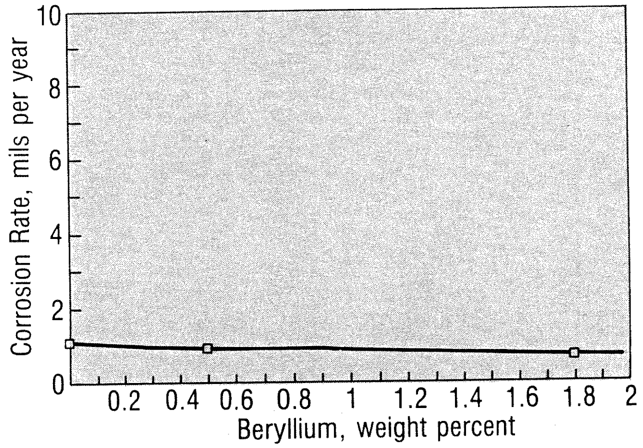
Low Velocity, depth 20 m/65 ft.

Figure 5- Effect of beryllium content on the corrosion of copper in low velocity seawater at 20 m depth[2].

Richards showed similar corrosion rates for C17200 strip which was annealed, 37 percent cold worked, and 0 or 37 percent cold worked and aged to peak strength. In a more detailed investigation of the influence of cold work and aging on corrosion for C17000, Tsunoda et al[2] show that corrosion is nominally the same for strip cold worked with up to 25 percent reduction and aged between 100 and 400 C (212 and 752 F). A similar amount of corrosion was also observed for material reduced 30 to 75 percent then aged to peak strength. These two statements cover the four individual conditions examined by Richards and found to have no effect on corrosion. Tsunoda *et al.*[2] also showed, however, that C17000 cold worked to a 50 or 75 percent reduction in either as-rolled condition or aged to less than peak strength either by under or overaging would accelerate corrosion. These investigators also showed that C17000 corroded similarly in shallow or deep ocean or in artificial seawater.

The results of the investigation conducted by Reinhart offshore near Port Hueneme, CA are discussed in different texts[3,4,5]. The corrosion rate was measured at depths of 1.5 m (5 ft) for 0.5 yr and 722 m (2370 ft) for 1.1 yr. Wrought C17200 sheet in a peak aged condition was examined along with similar sheet welded by MIG and TIG

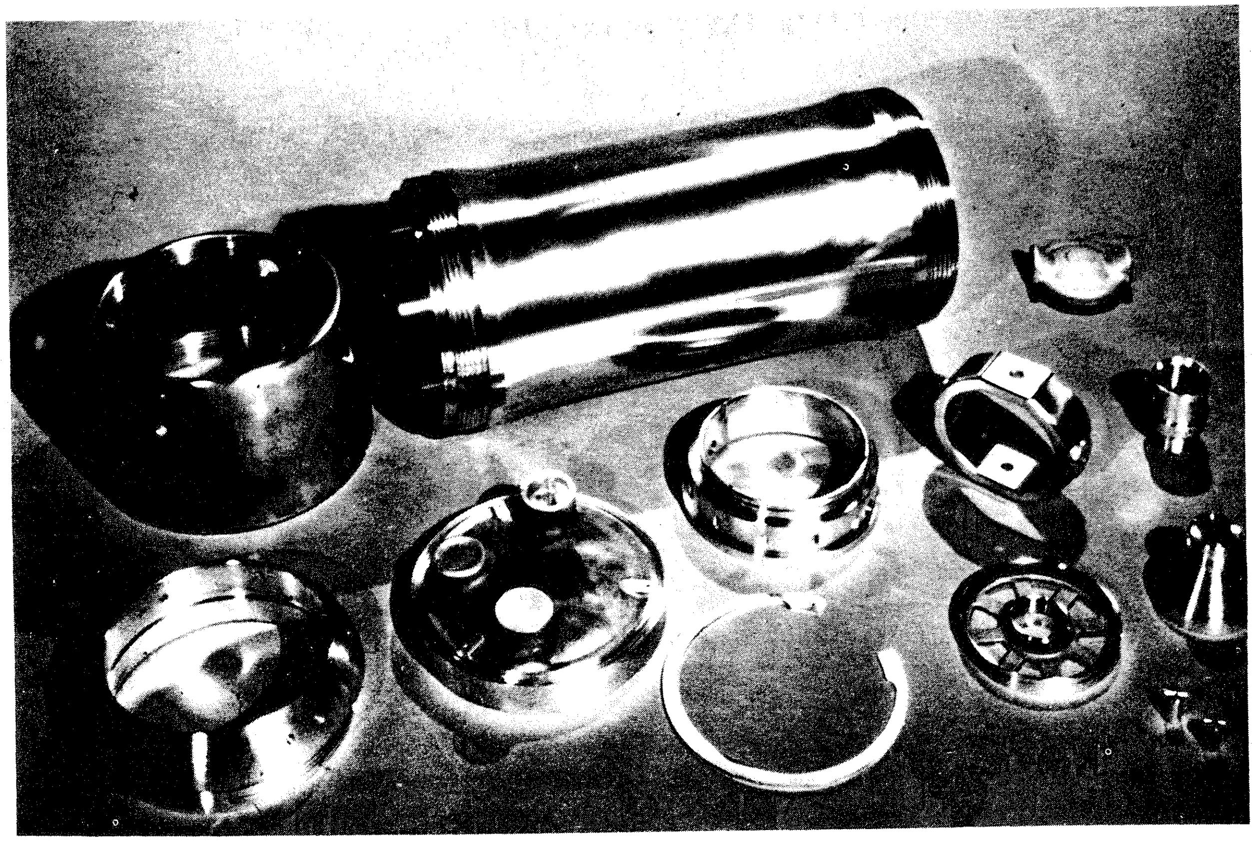

Figure 6- Beryllium copper components used in the underocean repeater housing.

techniques. As-cast C17200 chain was also exposed. The reported values were 0.1 mpy for the shallow/short exposure and 0.6 mpy for the deeper/long exposure. At 722 m specimens were also imbedded in the bottom sediments for 1.1 yr with measured rates of 0.5 mpy. No evidence of pitting or selective corrosion was observed.

Hohman and Kennedy[6] in work conducted in natural seawater at Harbor Island, NC also observed that the corrosion rate of C17200 decreased with exposure time from 2.2 mpy for one month exposure to 0.8 mpy for a six month exposure. They found that welded material behaved similarly to unwelded and that C17200 was resistant to fouling organisms and biological growth, Erosion-corrosion and cavitation resistance measurements concur with Richards[1] that the use of C17200 should be avoided for high velocity aerated environments. During the erosion-corrosion tests which were conducted, specimens of C17200 showed evidence of crevice corrosion and pitting in the crevice.

The investigation of Lennox, Peterson and Groover[7] was conducted in Key West, FL. They observed weight loss corrosion rates for C17200 similar to other investigators described herein but also reported that C17200 was subject to de-alloying in an intentional crevice. Initiation of crevice corrosion is a function of geometry. In a tight crevice significantly more aggressive solutions (high in Cu^{2+}) can develop and accelerate attack. In this situation de-alloying might possibly occur. However, beryllium copper, corroding freely without the effects of a crevice, has not been reported to suffer de-alloying and would not be expected to do so. These authors show that C17200 resists fouling such that only low pressure water washing is required to remove biological growth after a two year exposure.

Corrosion rates may vary among tests because such results depend on many environmental variables. For example, the chemical and biological composition of seawater differs with geographic location, depth from the surface and season. In general, copper alloys corrode more rapidly in warmer, and also faster flowing waters. Oxidizers such as cupric chloride and dissolved oxygen tend to increase corrosion. Clearly, test conditions will be difficult to reproduce at different locations, but in these studies[1-7] beryllium copper showed a similar corrosion rate of less than 1 mpy whether exposed in shallow seawater, deep ocean water or artifical seawater.

Aside from corrosion resistance, beryllium copper is well suited for undersea applications because it resists marine fouling. Like many other copper alloys, corrosion of the alloy causes release of cupric ions which are toxic to fouling organisms[8]. Consequently, underwater components of these alloys do not suffer from the voluminous or tenacious biological growth that unprotected steel, stainless steel or aluminum parts experience which significantly saves maintenance. Cathodic protection of copper alloys and beryllium copper lowers their corrosion rate but lessens their resistance to severe biofouling[7,9,10].

The submarine cable repeater housing is an example of an application where beryllium copper alloys perform particularly well. Each housing is approximately 1 foot in diameter, three and one half feet in length and weighs about 750 pounds. Figure 6 shows a repeater housing and the beryllium copper components that function inside it. Housings are stationed on the ocean floor, often half submerged in sediments, but the beryllium copper resists attack. When one telecommunications firm pulled up such a repeater housing after 25 years of service, it showed few signs of corrosion. A recent study[2] concluded that C17000 was the best of 30 metals examined because of its strength, workability and corrosion resistance.

2. Acids

Like other copper base alloys, beryllium copper is rarely recommended for structural components that are exposed to concentrated nonoxidizing acids. Any concentration of an oxidizing acid such as nitric is very corrosive, as are nonoxidizing acids such as hydrochloric and sulfuric when they contain oxidizers or oxidizing impurities, such as ferric, permanganate or dichromate ions or oxygen. Exposure to dilute solutions of nonoxidizing acids may or may not be acceptable, depending on the acid concentration, temperature and acceptable corrosion rate[10].

Although beryllium copper is not recommended for use in the presence of most concentrated acids, these acids are employed in the manufacture of beryllium copper products. For instance, dilute nitric acid or sulfuric mixed with hydrogen peroxide can remove oxides from the metal surface. Plating, soldering or any subsequent processing often demands an oxide free surface.

3. Alkalis

Dilute copper alloys generally resist rapid attack from alkali solutions. For example, short exposure of beryllium copper to a 50% sodium hydroxide solution at 130 C (265 F) does not cause appreciable weight loss. Copper alloys are suitable for handling anhydrous ammonia, but the ammonia must remain free of water or oxygen to avoid stress corrosion cracking. Copper alloys are not recommended for use in the presence of ammonium hydroxide which causes stress corrosion cracking for beryllium copper and many other copper alloys.

4. Organics

Beryllium copper responds much the same as commercially pure copper to organic liquids. Copper routinely handles glycols, alcohols, gasoline and most organic solvents[10]. The impurities present in these compounds frequently determine the corrosion rate rather than the organic compounds themselves. For example, traces of sulfides, acids, alkalis, salts or water may accelerate the rate of corrosion reactions by an order of magnitude.

Two plastics in particular, polyvinyl chloride (PVC) and room temperature vulcanized (RTV) silicone, were shown

Table 2: Comparison Of Copper Alloys In Atmospheric Corrosion After Two-Year Exposures

Alloy*	Atmospheric Corrosion (mpy)		
	Industrial	Marine	Rural
C12000[12]	0.04 (Newark, NJ)	0.06 (Kure Beach, NC) 0.02 (Point Reyes, CA)	0.03 (State College, PA)
C17200[12]	0.04 (Newark, NJ)	0.06 (Kure Beach, NC) 0.02 (Point Reyes, CA)	0.03 (State College, PA)
C17500[12]	0.05 (Newark, NJ)	0.05 (Kure Beach, NC) 0.03 (Point Reyes, CA)	0.03 (State College, PA)
C51000[13]	0.08 (East Alton, IL) 0.09 (New Haven, CT)	0.31 (Daytona Beach, FL)	
C51000[13]	0.15 (East Alton, IL) 0.07 (New Haven, CT)	0.30 (Daytona Beach, FL)	
C51100[14]	0.06 (Newark, NJ)	0.15 (Kure Beach, NC) 0.09 (Point Reyes, CA)	0.02 (State College, PA)
C72500[13]	0.08 (East Alton, IL) 0.08 (New Haven, CT)	0.15 (Daytona Beach, FL)	

*The superscript for the Alloy designation is the number of the reference for this data.

to corrode beryllium copper and other copper based alloys through the evolution of fumes. Other plastics such as acetal, Nylon 6/6 and Teflon emit volatiles under the same conditions, but these fumes do not affect copper alloys [11].

B. Atmospheric and Gaseous Media

1. Atmospheric Corrosion

Table 2 compares the outdoor atmospheric corrosion resistance of beryllium copper alloys C17200 and C17500 with phosphor bronzes, C51000 and C51100, and copper-nickel-tin, C72500. The corrosion resistance of the beryllium coppers equalled or exceeded the corrosion resistance of the other materials under industrial, marine and rural environments[12,13,14]. These rates are low and would be expected to decrease with longer exposure time.

Beryllium copper alloys also exhibit good resistance to corrosion at ambient temperatures for exposure to indoor or controlled atmospheres. This behavior is termed the shelf life of the alloy. For base metals used as electronic connector materials the relative shelf life can be measured by assessing the retained solderability of an exposed metal surface in a solder dip test.

After two years of indoor exposure at two different warehouse locations, unprotected beryllium copper strip was compared to strip which was inhibited with benzotriazole (BTA)[15]. Unprotected specimens of beryllium copper soldered as well as C51000 and C72500 by using a mildly activated rosin flux, but only 15 to 20 percent of these specimens passed a 95 percent wettability criteria. By using an activated rosin flux 50 to 75 percent of unprotected specimens of these three alloys passed the 95 percent wettability criteria. Inhibiting with BTA increased the percentage of beryllium copper specimens which passed the 95 percent wettability by a factor of the solderability of activated rosin fluxed specimens. Surface inhibition with a more aggressive flux can provide good solderability or effectively lengthen shelf life of beryllium copper.

2. Oxidation Behavior

The initial literature on elevated temperature oxidation behavior of beryllium copper was reviewed by Richards[16]. Since that time some experimental contributions were made to the understanding of the oxidation of binary beryllium-containing copper alloys[17,18,19,20]. Further work is necessary for understanding the oxidation behavior at short exposure times and of ternary and higher complexity alloys containing beryllium.

3. Hydrogen Sulfide Gas

A laboratory study[21] estabished the corrosion behavior of a number of commercial copper alloys in a humid ambient temperature environment containing 3 ppm of hydrogen sulfide. Beryllium copper C17200 exhibited about five times the resistance to sulfidation under these accelerated test conditions as pure copper at the low and moderate levels of exposure, Figure 7. The level of exposure is defined as the product of hydrogen sulfide concentration and exposure time. A moderate level of exposure in this test, about 10 ppm hr, is reported to be roughly equivalent to the cumulative exposure to hydrogen sulfide occurring during one year in an average urban location. Above this exposure level, beryllium copper behaves about the same as copper, cupronickel C71500 and phosphor bronze C51000. These same authors show by results conducted in this paper[21] and a subsequent paper[22] that C17200 is relatively sulfidation resistant for the low level of alloying elements employed. Generally, the corrosion caused by hydrogen sulfide or sulfur dioxide is significantly enhanced by moisture[10].

4. Halogens

Halogen gases such as fluorine, chlorine and bromine require moisture to attack copper[10]. Moist chlorine is especially corrosive to copper at elevated temperatures. Copper alloys including beryllium copper have been used in bellows and diaphragms for instrumentation exposed to the fluorine containing environment of uranium isotope separation and enrichment processes.

C. Galvanic Corrosion

Galvanic corrosion occurs if two dissimilar metals are joined to establish electrical contact between the metals in a conductive solution. The galvanic series provides a practical indicator of which member of this galvanic couple will corrode more rapidly in seawater, the more active member with the more negative electrode potential. The galvanic series shown in Table 3 ranks metals and alloys by the measured electrode potentials with the most noble ones listed at the top[7,23].

To illustrate, beryllium copper C17500 will corrode when galvanically coupled with the more noble metal such as platinum. Conversely, this alloy will be protected when galvanically coupled to more active aluminum alloys, zinc and magnesium.

Severe corrosion results from large differences in potentials between the coupled metals or if the exposed area of the cathode or noble alloy greatly exceeds the exposed area of the anode or active alloy[24,25]. No significant galvanic corrosion results from coupling beryllium copper to the other copper alloys found in this table because the differences in potential between these alloys are small.

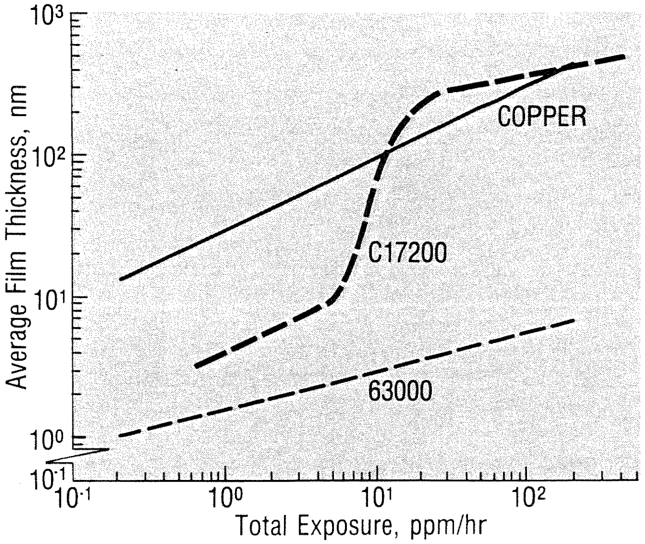

Figure 7- Effect of the total exposure on the sulfide film which forms on copper and beryllium copper[21].

Table 3: Galvanic Series Of Metals In Seawater

Alloy Designation	Electrode Potential[7] (volts vs SCE)*	Electrode Potential[23] (volts vs SCE)
Platinum		+0.35 to +0.2
Tantalum	-	about +0.2
Ti and Ti alloys	-	+0.06 to -0.05
Passive 300 series stainless steels......	-	0.00 to -0.15
Monel 400 & K-500 ...	-	-0.04 to -0.14
C52400	-0.168	
C17200	-0.201	
C71500	-0.219	-0.13 to -0.22
Copper	-0.219	about -0.14
C65500	-0.224	-0.24 to -0.27
C61400	-0.200	-0.30 to -0.40
C17500	-0.231	
C26800	-0.237	
C26000	-0.242	
C44300	-0.237	-0.25 to -0.34
C60800	-0.248	
C70600	-0.256	-0.21 to -0.28
C46400	-0.255	-0.30 to -0.40
C22000	-0.255	
C23000	-0.290	-0.20 to -0.40
C28000	-0.341	
Active 300 series stainless steels......	-	-0.35 to -0.57
Plain carbon steels ...	-	-0.60 to -0.70
Aluminum alloys	-	-0.70 to -0.90
Zinc	-	-0.98 to -1.03
99.99% Aluminum	-	-1.25 to -1.50
Magnesium	-	-1.60 to -1.63

*Electrode potentials were converted from the original authors' reported values for Ag/AgC1 reference electrode to SCE.

Table 4: The Effect Of Ammonia Concentration On The Rate Of Stress Corrosion Cracking[26]

NH_3 (torr)	Environment H_2O (torr)	Relative Humidity (%)	Time to Failure (hours)	Crack Growth (mm)	Average Crack Velocity[1] (mm/hour)
			K=47 $MN/m^{3/2}$		
130	21	89	12.4	2.5	2x10^{-1}
8	24	100	1236	2.5	2x10^{-3}
1	24	100	no failure in 1014 hours	0.12	<2x10^{-5}
			K=31 $MN/m^{3/2}$		
130	21	89	19.5	4.1	2.1x10^{-1}
8	24	100	1320	3.8	2.9x10^{-3}
1	24	100	no failure in 1014 hours	none detected	<2x10^{-5}

1. Based on (total crack growth)/(time in test).
2. All crack growth was observed during the first 24 hours after loading.

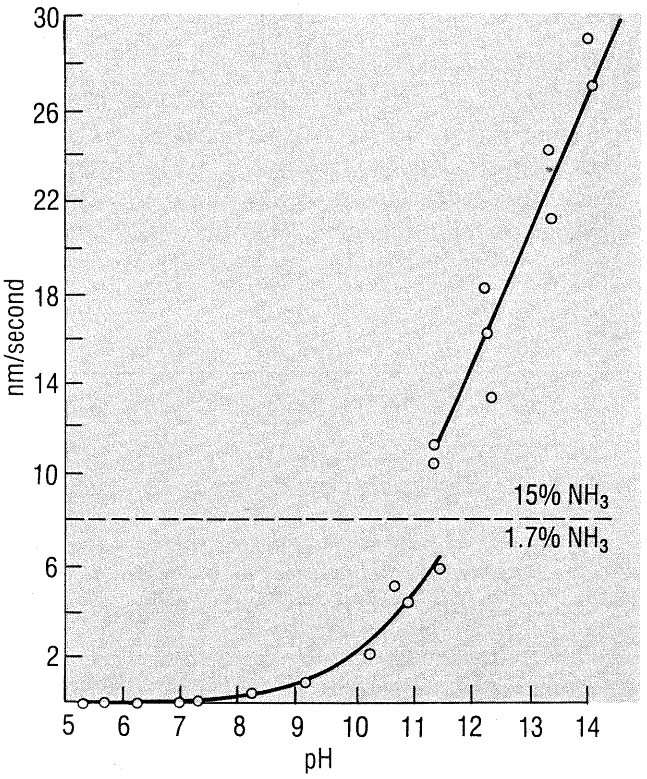

Figure 8- Effect of pH on the crack growth of a stress corrosion crack for two ammoniacal environments, 1.7 and 15% NH_3[28].

D. Stress Corrosion Cracking

Stress corrosion cracking (SCC) refers to the sudden failure of a metal or alloy in the presence of a specific corrosive environment at a static stress below the normal fracture stress. Failure of this type can be insidious because most of the metal surface may appear unattacked while the applied stress is within a permissable range. Specific environments cause stress corrosion cracking for particular metals and alloys. For example, chlorides or caustics stress corrosion crack austenitic stainless steels but have no effect on copper alloys. Conversely, ammonium hydroxide or ammonia with high relative humidity causes SCC in copper alloys but does not affect stainless steels. Copper alloys with a high copper content, like beryllium copper, generally show the highest resistance of all copper alloys to SCC from ammonia. Other substances such as mercury and mercuric salts induce liquid metal embrittlement in copper alloys that is sometimes mistakenly labelled SCC. Another related phenomenon, corrosion fatigue, occurs if a particular environment decreases the fatigue life of a component under cyclic stress.

For stressed copper alloys SCC occurs if three critical environment constituents are available: ammonia, a high relative humidity, and oxygen. From the work of Magnani[26], Table 4 shows that increasing the ammonia partial pressure from 8 to 130 torr (1070 to 17,300 Pa) reduces the time to failure of beryllium copper by two orders of magnitude. Increasing the relative humidity between 51% and 89% also shortens the time to failure by two orders of magnitude. Sylwestrowicz[27] earlier also showed that faster initiation and growth of stress corrosion cracks accompanied higher humidity conditions. Magnani[26] also showed that without oxygen a loaded specimen showed no crack growth after 800 hours, while other identically loaded specimens failed after 12 hours with oxygen at a partial pressure of 150 torr (20,000 Pa).

Another factor that significantly affects the rate of crack propagation in beryllium copper is the pH of the liquid environment. Figure 8 demonstrates that for C17000 SCC occurs in solutions with a pH greater than 7.4 and crack propagation procedes rapidly as the pH becomes more basic[28]. Sylwestrowicz discusses the mechanistics of SCC fractures of beryllium copper through a series of papers[29-33].

In rare instances, copper components in electronic assemblies, including beryllium copper, unexpectedly fail as a result of stress corrosion cracking. Such fractures usually occur under hot (greater than 160 F or 71 C), humid conditions and the source of ammonia can be a plastic material. Improperly specified or cured plastics in an assembly emit gases containing ammonia. Copper alloy components with a residual or significant applied stress under these conditions are susceptible to SCC failure.

Beryllium copper is also most susceptible to delayed failure by liquid metal embrittlement by mercury. Material hardened, by cold work or aging or both, is most susceptible. Once liquid mercury penetrates the grain boundaries the time to failure is short[34].

One Demanding Application

As introduced beryllium copper alloys are engineered materials. Some of the significant properties inherent in these alloys are the resistances to galling and wear, good machinability, high thermal conductivity, low magnetic permeability and for certain environments good corrosion resistance. The strength, ductility and electrical conductivity are tailored by processing and heat treatment to meet the requirements of the particular application. Alloy C17200 is needed for nonmagnetic drill stem components for oil and gas well drilling, as in Figure 9. Many of the above inherent properties of this alloy are necessary for this demanding application.

In certain locations in the world high chloride drilling fluids are employed. Alloys, such as austenitic stainless steels, may be subject to SCC in such an environment. This type of failure is unpredictable and costly. Laboratory tests indicate that C17200 resists chloride SCC, while three nonmagnetic stainless steels failed under similar test conditions[35].

Weight loss corrosion for this alloy should also be considered in designing a component for downhole drilling environments. Intermittent and brief exposures may subject the components to hot brines saturated with carbon dioxide and hydrogen sulfide. Again, laboratory studies[35] indicate that the corrosion of C17200 is general in nature, not localized or selective. Because the corrosion is uniform, it is amenable to engineering design, such as a corrosion allowance. Acceptably low rates were found (<30 mpy) for temperatures up to 149 C (300 F) in synthetic seawater in equilibrium with gas containing 1% hydrogen sulfide. For 10% hydrogen sulfide and up to 66 C (150 F) rates were less than 20 mpy. In a sweet environment with an additional 10% potassium chloride for temperatures up to 149 C (300 F), the rates were 8 mpy or less. These conditions may be more severe than the most frequently occurring drilling environments and suggest that beryllium copper may be used with adequate engineering.

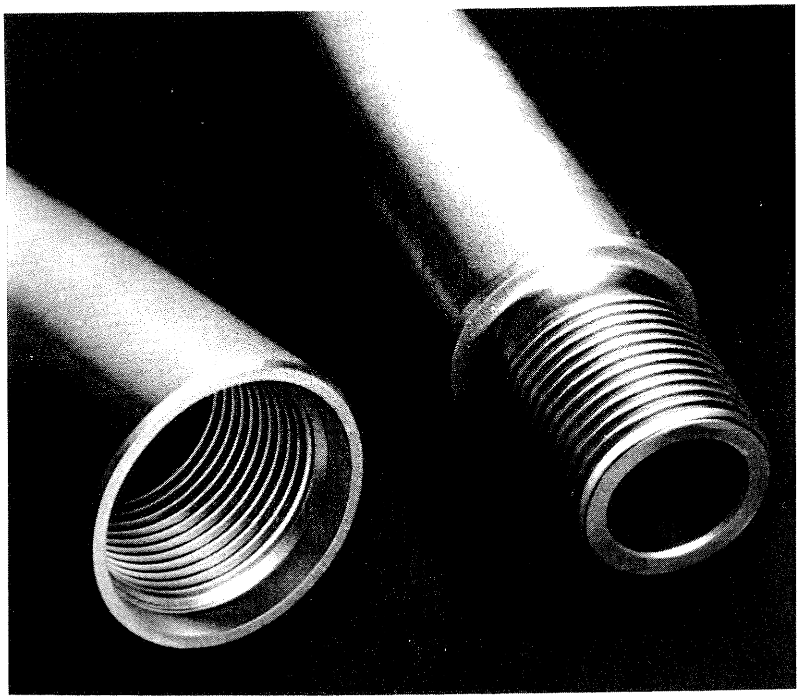

Figure 9 - Alloy C17200 is needed for nonmagnetic drill stem components for oil and gas well drilling.

This technical memorandum broadly describes the corrosion resistance of beryllium copper. These alloys generally resist corrosion as well or better than pure copper. For example, beryllium copper shows good resistance to corrosion in low and moderate velocity seawater. In addition, beryllium copper largely avoids biofouling. These factors plus high strength and good machinability make beryllium copper suitable for many marine applications.

Beryllium copper resists atmospheric tarnishing in many indoor and outdoor environments. This behavior is an important characteristic for electrical and electronic components which should have a long service or storage life. These alloys also resist stress corrosion cracking by ammonia for limited humidities, oxygen and ammonia contents.

Alloy C17200 meets the highly demanding conditions encountered during drilling of oil and gas wells. This alloy resists galling and chloride stress corrosion cracking, and as a result, beryllium copper finds growing use in drill collars, subs and instrument housings. Beryllium copper combines desirable physical and mechanical properties with good corrosion resistance.

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