

Fundamental Characteristics  
of

# REVERE COPPER

and its alloys



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## **FOREWORD**

The following information has proven of such interest and assistance to Revere trainees that we felt others desiring information on copper and its alloys also would find it useful.

We realize that this is no course in metallurgy and do not expect that its study will change a non-technical man into a trained technician. It should, however, help us to be more appreciative of the contribution made by the technical man and permit us to more readily recognize how and when to request his aid.

We wish to express our sincere thanks to the individuals who have devoted their time and effort to this work.

Revere Copper Products Inc.

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## REVERE COPPER AND ITS ALLOYS

Copper is the basic metal on which Revere was founded. Some of its physical and chemical characteristics should be understood as these are factors which control its use by the customer. Some of these important properties are:

1. Copper easily forms useful alloys with other metals, each alloy having its individual characteristics adapting it to a virtually unlimited number of applications.
2. Copper and many of its alloys are able to withstand severe working at room temperature—due to their high ductility and malleability (ability to be rolled, drawn, hammered or forged).
3. Copper and its alloys show remarkable resistance to corrosive agents such as moist air, water, salt water, non-oxidizing acids, alcohols, and many chemical media.
4. Copper itself is outstanding in its ability to transmit electrical energy and heat with a minimum of loss. In this respect it is far superior to any other metal commercially available.
5. Copper and its alloys show a remarkable color range—from red, through various yellows to silver colored alloys in the case of the nickel alloys. That's why copper or one of its alloys is often preferred, particularly in the jewelry trade where gold is the only other colored metal.
6. Copper metals are readily welded, while the majority of them are easily joined by soft soldering or by self-fluxing brazing alloys—a most important factor in making auto radiators, heater cores and many air conditioning components.

Metals most commonly alloyed with copper are zinc, tin, aluminum, silicon and nickel. Of the various alloys,

the brasses (copper and zinc in varying percentages) are the best known.

The brasses commonly used range from 95% copper—5% zinc to about 55% copper—45% zinc.

This range may be divided into those brasses with a copper content above approximately 64% and those with less than this percentage of copper. The former are known as the “alpha” brasses, the latter as “beta” brasses. Actually this means a mixture of alpha and beta brass, since all beta is uncommon.

The alpha brasses are best known for their ability to withstand a great deal of cold working (drawing, rolling, etc.) without annealing. In this respect they closely resemble copper. They show somewhat higher strength than copper—this increasing with the decrease in copper content. Their ductility is good—the combination of ductility and strength being even better than that of copper.

These brasses may also be hot worked although in this respect they are slightly, by modern standards, inferior to the beta brasses. Their corrosion resistance is reasonably good yet in some respects inferior to copper; depending upon conditions. The electrical and heat conductivity is fair—again decreasing with the decrease in copper content.

These brasses exhibit a wide range of colors—from the red-gold of 95% copper-5% zinc through the gold of 90% copper-10% zinc and 85% copper-15% zinc to the bright yellow shown at 70% copper.

Some of the common alpha brasses and their commercial names are:

Gilding, 95% (2 10)\*  
Commercial Bronze, 90% (220)  
Red Brass, 85% (230)  
Low Brass, 80% (240)  
Cartridge Brass, 70% (260)

\*These and subsequent numbers used in parenthesis (without prefix letters such as “B”, etc.) throughout this booklet, are employed by the Copper Development

Association, Inc. to identify the various copper alloys. For example: those with more than 93% copper are numbered 100 to 199 while non-lead brasses are 200 to 299.

### Electrical Conductivity of Copper

When we speak of electrical conductivity as being high or low we are referring to electrolytic tough pitch copper (110) as the standard at 100% IACS (International Annealed Copper Standard). Present day purity is high enough that conductivity may be over 100% and for certified OFHC (101) it is close to 102%. The only other metal over this is pure silver at about 106%. A low value among Revere alloys would be 4% as for 70/30 Cupro-Nickel (715). Metal alloys used for resistance heating (electric stoves, irons, etc.) have conductivities far less than 1%, and measurements are made in terms of resistance rather than conductivity. (A few examples are listed in table that follows).

Heat conductivity numbers are mathematically related to electrical conductivity so that for much practical testing and checking, the electrical conductivity is determined because it is so much easier to perform.

### Electrical Conductivity

Material	CDA Alloy No.	% IACS.
Electrolytic Tough Pitch	(110)	100.8
Deoxidized Copper .DLP	(122)	85
Gilding Metal .95%	(210)	56
Commercial Bronze .90%	(220)	44
Red Brass .85%	(230)	37
Cartridge Brass .70%	(260)	28
Admiralty	(443)	25
Aluminum Bronze (D)	(614)	14
Cupro-Nickel .10%	(706)	9
Aluminum		50-64
Low Carbon Steel		14-17
Stainless Steel 18-8		4
Pure Nickel		25
Pure Zinc		28
Pure Tin		15

[6]

The beta brasses (64% copper and less) are especially noted for their ease of working in the hot condition. However, they are not susceptible to extreme cold work and in the lowest range commonly used (about 55% copper) the amount of cold work that can be done without annealing is relatively small. These brasses exhibit comparatively high tensile strength and qualities of hardness. They are not used where maximum corrosion resistance or electrical conductivity is desired although they are better than many other materials in this respect. Their color is a surprising feature. As the copper content decreases under 62% (the beta content increases) they become more and more red so that at 58% copper the color is a close match for Commercial Bronze, 90%. This is useful in that complicated architectural shapes may be made by hot extrusion, and used with rolled panel sheets of Commercial Bronze, 90%. Common beta brasses and their commercial names are:

Muntz Metal 60% (280)  
Architectural Bronze (385)  
Manganese Bronze (675)

The next common series of brasses are those intended for free-machining purposes. These leaded brasses are numbered from (300) to (398) although the several "Manganese Bronzes" are in the (600) series.

The free-machining property is brought about (in the case of the brasses) by the addition of lead. This is not soluble in, nor does it enter into, chemical combination with the brass. Instead, it collects in small particles throughout the brass. Upon machining, these particles cause the metal being cut off to form into small chips rather than in long spirals. This prevents fouling of tools and the lead helps lubricate the tool face.

All the leaded brasses may be hot worked but those with about 1.5% lead or higher must have support as in a die (extrusion or forging). At high temperatures, the lead within the metal is molten and in the ordinary processes of hot rolling or piercing, breakage would occur.

Leaded brasses show relatively poor cold working properties.

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They will all withstand a limited amount of cold work, but as the lead content increases the workability decreases. Some alpha brasses with limited lead content will withstand cold working and still show fair machining properties. These might be called “compromise” alloys. In general, however, leaded alloys are not intended for severe cold working and should be avoided if this characteristic is paramount.

Of special interest in the free-machining metals is Tellurium Copper (145). Unlike lead, tellurium forms a chemical compound with copper—a copper telluride—which is in turn insoluble in copper and lies in small particles dispersed through the copper as does the lead in brasses. Tellurium Copper may be hot worked, and will accept cold working but does not compare with other coppers in this respect. Tellurium, in the quantities used, does not appreciably affect corrosion resistance, electrical or heat conductivity or color. Sulfur copper (147) is similar to Tellurium Copper in properties and has an oxygen-free base.

A third series of alloys are those containing tin, and are numbered in the (500) series, including those with lead for free machining. Tin is added for one of two effects—added strength or corrosion resistance.

In this series are the true bronzes. These are called Phosphor Bronze and contain up to 10% tin. The term phosphor is derived from the fact that the alloy is deoxidized with phosphorus. However, the metal is essentially tin and copper.

These alloys show excellent cold-working properties and will exhibit greatly added tensile strength over that of copper. Their resistance to fatigue (alternating stresses) is very high while their resistance to corrosion is excellent. Their electrical and heat conductivity is low.

Tin is added to other alloys in this series in small percentages (about 1%) to increase corrosion resistance. When added to 70-30 brass, we have Admiralty (443)—long used for resistance to both fresh and salt water corrosion, as in heat exchanger tubes. When added to Muntz Metal, we have Naval Brass (464). These alloys do not differ greatly from the original brasses to which the tin has been added except to increase resistance to corrosion. The alloy

may be slightly harder.

There are a number of special alloys which have particular properties such as high strength or corrosion resistance, or both, which are numbered in the 600 series. Of these there are:

**Aluminum Bronzes** of a large variety of compositions—those with less than 7% aluminum are ‘alpha’ alloys with excellent cold-working properties such as 5% Aluminum Bronze, a fine corrosion-resistant tube for salt and brackish water service. Those with more than 7% aluminum usually also have added iron, manganese and nickel in varying amounts. They are among the best high-strength corrosion resistant alloys available in the copper metals group.

**Aluminum Brass** (687), Revalon®, is essentially 78% copper plus 2% aluminum and the rest zinc—a moderately-priced tube alloy quite resistant to salt water, as used aboard ship and in desalination plants.

The last series of Revere alloys is the (700) group—the Cupro-Nickels and the Nickel Silvers. Two alloys are important - Cupro-Nickel 10% (706) and Cupro-Nickel 30% (715). They are standard alloys for marine use in resisting salt water corrosion and/or erosion. Cupro-Nickel 10% (706) is also non-fouling. They hot and cold-work well and are produced in the form of sheet, plate, tube and rod. The Nickel Silvers are copper-nickel-zinc alloys and are generally used as a base for silver plate. Their strength and corrosion resistance are good and, except for the leaded Nickel Silvers, their workability, hot or cold, is good. The color is silver-white. In all cases, the presence of nickel reduces, electrical and heat conductivity. Nickel Silvers are excellent spring materials and are so used in quantity.

The coppers themselves may be considered to be a separate and distinct series of alloys.

The most common form is electrolytic tough pitch copper (110) used for electrical work in bus bar, commutator, wire and strip. It is also used to a great extent in sheet form for roofing, general sheet metal work and

processing equipment where both corrosion resistance and heat conductivity are required. Strip copper in large quantities is used for automobile radiators and heaters. Its unique color is important for decoration.

There are also special Coppers:

**Phosphor Deoxidized Copper** - This copper shows the presence of a small amount of phosphorus. Electrical conductivity is reduced. Workability, hot or cold, is very good. This material is used chiefly in the manufacture of seamless tubes and as sheets for coppersmithing and welding.

**Oxygen-Free, High Conductivity Copper** (OFHC)\* (101- 102) - is used in vacuum tubes and electronic devices where high purity, lack of oxygen and freedom from hydrogen embrittlement are necessary. OFHC also is readily welded, and miles of the inner conductor of ocean cable are made this way.

Ductility is very high and hardening rate is low so that extensive cold working can be done.

**Silver Bearing Coppers** (113, 114, 115, 116) - find special application for parts which must be fabricated, using solders which will otherwise soften the metal. Silver also prevents re-crystallization in service, and increases the long-time strength at moderately elevated temperatures.

Other elements are also added in small amounts, such as cadmium, chromium and zirconium for moderate increases in strength.

**Beryllium Coppers** (172, 173 and 175) - are very special heat-treated alloys with very high strength, but are quite expensive.

\*OFHC is the registered trademark of the high purity oxygen-free copper produced by American Metal Climax, Inc.

## COLD WORKING AND HARDNESS

Our second basic characteristic making copper and many of its alloys valuable is the ability to withstand severe cold working, i.e., high ductility and malleability. In other words, they can be drawn or rolled to a remarkable degree at room temperature.

As we work copper in the cold condition, hardness is imparted to it. In fact, the hardness imparted to the metal increases as the amount of cold working increases.

Incidentally, this is the only way that copper or an alpha brass may be hardened. It cannot be heat-treated to obtain hardness as can the steels. This is true not only of copper but any pure (unadulterated or unalloyed) metal, i.e., aluminum, iron, magnesium. There is no "lost art" of tempering copper despite the wide publicity given its alleged existence. Any "hard" copper made by the ancients was made hard by cold work, by the presence of impurities making an alloy, or both.

As we are considering the ability of copper to be cold worked, we should have some basic understanding as to:

1. What happens within the metal.
2. What makes it become harder under these conditions.
3. Whether or not this hardness is of value.

A piece of soft copper may be considered as being made up of innumerable crystals of copper. A crystal of copper, if it could be produced under ideal conditions, would take the form of a perfect cube. This cube might be compared with one of a pair of dice. At each corner of this die is a molecule of copper. On each face of the die—located in the position of the one spot—or "snake eye"—is another molecule of copper. This arrangement of molecules is called a face-centered lattice. Acting between these molecules are stresses—each molecule having an attraction for those about it. When the opportunity arises for the molecules to move about freely, they will arrange themselves in the position in

which the minimum of these stresses occurs—much as the molecules in a rubber ball return to their natural position when you stop squeezing it. This freedom of movement is brought about by heating processes, and during this condition the molecules take the position of least stress, i.e., the cubical, face-centered lattice described above.

Now starting with this condition—namely, a material with maximum freedom from stress (or in other words, soft metal), let us see what happens when any cold work—or cold deformation—occurs.

With sufficient stress (application enough to overcome the stresses holding the molecules in position) the crystal is fractured and part moves or slips along on the other part. To illustrate, if we consider our crystal as a pack of cards we have taken half the deck and slid it along the other half for a slight distance.

In this area where slippage has occurred, the orderly molecular arrangement has been destroyed and the intermolecular stresses are increased. Because of this increased stress there is now a greater resistance to further deformation and the metal in this area is harder. As further work is done on the crystal, more and more fractures and slippages occur until we have completely broken up the former orderly or crystalline arrangement of the molecules. The metal may now be said to be “full hard” or completely cold worked. Referring to our deck of cards once again, all the cards have been moved in relation to those about it as a result of numerous cold workings. The fractures just described are called slip-planes”, an amorphous material that has no crystal structure.

This then is the theory of cold working, and refers not only to copper and its alloys but other metals as well.

To digress for a moment into factors other than cold working, which affect the hardness of metals, let us consider the case of the brasses wherein the addition of zinc to copper increases hardness.

Let us return to the illustration of the copper crystal wherein the molecules align themselves in a cubic manner—a molecule at each corner of the cube and

one centrally located on each face. With the addition of zinc, one or more of the molecules of copper is displaced by molecules of zinc. The molecules are still in approximately the same position—but the forces of attraction of a zinc molecule are not the same as those of a copper molecule. The crystal is not as well balanced with greater stresses set up between molecules. As usual, where stresses are increased so is the resistance to deformation increased proportionally. To put it another way, we now know that the metal is harder.

If we should continue to add zinc, we would eventually cause such increases in stresses that the molecules would no longer take the position described before. We would still have our cube with a molecule at each corner, but instead of one on each face, we now have one deep inside the body of the cube. This is a ‘body-centered lattice’. The crystal might be said to be compact with very great internal stresses—in other words—hardness. When this condition is reached, we have beta brass.

Other metals will substitute for copper in our original cube as does zinc—but the stresses that are set up vary with different metals. For example, aluminum sets up strong stresses in low percentages making the strong aluminum bronze. Silicon is similar—making the silicon bronzes or Herculoys.

The cold working principle used with these alloys is practically the same as that of copper itself insofar as the crystalline derangement is concerned. Of course, with greater inherent hardness, stronger external forces are required for fabrication.

Up to now, we have described the basic changes taking place within the metal when it is cold worked. Let’s consider the practical effect of cold working.

In our discussion, we carried the cold working to the point of complete crystal deformation. In practice this is seldom done. In addition to certain effects this might have upon subsequent processing, it is not an economical procedure as the metal becomes very hard and processing is difficult. Copper may be cold reduced more than 95% without annealing.

It is clear by now surely, from all the preceding

comments, that with increased cold work, we obtain increased hardness. This means that with limited work. we can produce a metal slightly harder than soft and by additional work, we can increase this hardness all the way up to the point of the maximum possible. With this control, we can supply a complete range of tempers within the limits for a given metal, to provide for successful use in a wide variety of applications.

Let us consider some of these applications. As an example, a relatively soft material might be desired with which the manufacturer wishes to do considerable cold work himself—such as producing deep drawn or spun articles. A hard material would be indicated where maximum strength is required and little or no cold work is to be done. In between these two extremes lies a wide variation of possible tempers—any of which may be desired. Consider the case of switch clips. Here a strip of metal is bent to form a “U”. It must be soft enough to withstand the bend—and yet springy enough to insure good contact with the switchblade when it is pushed into the “U” of the clip.

All this means that the customer and the supplier must have a common ground of understanding. The former must have some means of indicating to the supplier the degree of hardness he requires. The latter must have means of insuring that his product meets the degree of hardness specified. We must have, therefore, a set of standards understood by everyone concerned.

There are several organizations that issue specifications which serve as standards for various products, among them, The American Society for Testing and Materials (ASTM), the Society of Automotive Engineers (SAE), the American Society of Mechanical Engineers (ASME) and the U.S. Government Military (MIL), and Federal.

ASTM is most used in the brass mill industry with about 200 specifications covering many alloys and types of products. Some typical ones are:

- (a) Copper Bus Bar (B 187)
- (b) Free Cutting Brass Rod, Bar and shapes for use in Screw Machines (B 16)
- (c) Seamless Copper Tube, Bright Annealed (B68)

- (d) Seamless Copper Water Tube (B88)
- (e) Aluminum Bronze Plate (B 169)

Various methods of testing are also established such as:

- E 36 Chemical Analysis of Brasses
- E 6 Methods of Mechanical Testing

The standards for Copper Metals all have the prefix B, as are those for other nonferrous materials as aluminum, magnesium, zinc, etc. Steels would be A, for Cement, C, and many organic compounds as rubber, textiles, etc., would be D. The copper metal standards, as well as others, are written and approved by both producers and users, thus representing a consensus of all interested parties. There may also be specifications set up by individual users, which may deviate from similar ASTM specifications to accommodate peculiar requirements of the buyer.

It has been the custom in the industry to describe cold worked tempers for sheet (strip) and wire as one eighth ( $1/8$ ) hard, one quarter ( $1/4$ ) hard, half ( $1/2$ ) hard, etc. This represents the amount of cold reduction in thickness for strip (by area for sections as rod, wire and tube) in reducing metal to specified gauge. In strip rolling it is described in terms of Brown and Sharp gauge numbers.

For example, .064” thick strip is 14 B & S gauge. If we cold reduce it 6 B & S numbers, the final gauge will be .032. It will be called Extra Hard and represents about 50% cold work. (The B & S gauge system has about 11% difference in thickness between each gauge number. Consequently, counting gauge numbers from the initial thickness to the final one is an easy way of describing the amount of cold work.)

The majority of the specifications in use require these various conditions of cold work to be measured by various means, which will now be described.

A test for surface hardness is the easiest one to

make and may be used as a complete control device or as an advisory one. The most common in our industry is the Rockwell hardness test which measures the degree of penetration of a ball or diamond cone into the metal in a certain way; the deeper the penetration the softer the metal. The values are expressed as B (100 kilogram load), F (60 kilogram load), 30T, 15T and so on. The higher the number from 1 to 100, the harder the material, but one must know the load or scale used to understand the value. There are others as Brinell, Knoop, Vickers, etc., for other materials or for special measuring needs.

Within certain limits, they may be converted one to the other.

The most complete description of a metals' properties are obtained by determining the Ultimate Tensile Strength, the Yield Strength (various), the elongation and, for solid sections like rod and wire, the reduction of area. All of these will result in using a tensile testing machine which applies a steady controlled force to a suitably prepared specimen. It first stretches - the amount of which may be recorded automatically on a graph called a stress-strain curve - and then breaks the piece. Ductile materials may stretch, or "neck down" to a remarkable extent; brittle materials will not.

Ultimate tensile strength is the pounds required to break the metal divided by the area of the sample before fracture and expressed as pounds per square inch (PSI), though it is usually expressed as KSI; . . . 1 KSI equals 1000 lbs/sq. in.

For annealed copper the value will be between 30,000 and 33,000 PSI, and for Full Hard (4 No's) about 45,000 PSI (or 45 KSI); spring temper 5% Phosphor Bronze (510) would be about 100,000 PSI (or 100 KSI); Beryllium Copper (170) about 200,000 PSI (200 KSI).

The Yield Strength is not determined for specification purposes as often as tensile strength, but is needed in design of many things since it is a measure of the ability to withstand a load or stress without being permanently deformed - in other words it absorbs the load without permanent damage. The methods of determining the several values as 0.1 and 0.2% offset yield strengths are outlined in ASTM specification E 8.

The same sample used for getting the tensile strength is marked in the center portion so that the amount of total stretch to breakage can be measured. The difference between the original distance (usually 2") and that after breaking, divided by the original (x 100) is called % of Elongation - the original marked distance must always be specified since it is not necessarily always 2"; and the meaning is different for different gauge lengths. Very ductile metals as copper, cupro-nickel, etc., have values over 50%. The number becomes less as material is cold worked; after 95% cold work, copper will be only about 1%.

The reduction in area represents the amount the specimen "necks down" - or stretches out like taffy candy being pulled.

Measurement is made by matching the broken pieces and getting the diameter at the smallest place. The difference between the area at this point and the area of the smallest part of the original sample divided by the original (x 100) is the % of Reduction in Area. For very ductile materials the value is over 60% and for brittle materials, less than 10%.

Both the % of Elongation and the % of Reduction Area are useful in determining the ability of a metal to be cold worked to make strip by cold rolling, bolts by cold heading, rods by cold drawing and so on.

## **ANNEALING OR RECRYSTALLIZATION**

We have discussed in very brief manner the theory of cold working of copper in the light of what happens within the metal during the process of drawing, rolling, or other means of cold deformation. In general, it was pointed out that cold working increases hardness, and that this increase in hardness was due to distortion of the orderly molecular arrangement resulting in increased stresses between the molecules. In other words, hardness is due to increased stress.

It was pointed out too, that it is seldom commercially practical to cold work the metal to the utmost degree, but rather it was usually desirable after a certain degree of cold work—to soften the metal by relieving the stresses set up and begin over again. This softening process is called annealing and is brought about by subjecting the metal to moderate or high temperatures, say 5000 to 1600°F. depending upon alloy. Let us consider a piece of copper that has had some cold work done upon it. It is hard. The molecules are not in orderly arrangement. There are stresses between them. The crystals, which are the result of orderly molecular arrangement, have been broken up and no longer exist as such. The molecules would, if they could, return to their original arrangement. However, in the cold condition they do not have sufficient freedom of movement to do this. If we can increase their energy sufficiently, they will have sufficient force and freedom of movement to rearrange themselves.

Heat is energy, nothing more. It may be considered an indication of molecular movement. At absolute zero (a low temperature we have never reached) matter is believed to be absolutely inert—in other words, there is no molecular movement. As we increase the energy of the molecules (by heating) the molecules have motion. At first they merely “vibrate” in the same relative position, but as we increase their energy (their temperature) they have more and more freedom of movement—finally becoming a liquid—or even a gas.

Returning now to our hard copper we apply heat. As we do so, the molecules move faster and faster—finally

reaching a point at which they have enough energy to overcome their relatively fixed position and they can now realign themselves in the way they choose—namely, in the orderly crystalline arrangement which gives freedom from stress or to form soft metal.

The temperature at which the system may be restored to minimum energy is always fixed for a given substance with a given degree of internal stress (degree of cold work). This point is called the recrystallization temperature and is just what the name implies—the minimum point at which the molecules will rearrange themselves and form new crystals. There is nothing mysterious about it—it is just a given temperature for a certain substance that has been worked to a given degree.

However, certain complications arise. We find that we can control the size of the crystals into which the molecules form themselves by controlling conditions.

If recrystallization temperature is just barely reached and held for only a short time, the crystals formed will be small. If that same temperature is held for long extended periods of time, the crystals will become relatively large. On the other hand, if the recrystallization temperature is considerably exceeded, the molecules have great freedom of movement and in a comparatively short time form into large crystals.

Therefore, if we wish to control the crystal size we must control (a) the amount of previous cold work, (b) the temperature and (c) the time at that temperature. Note that we say the “time at that temperature” because the time in the furnace itself will vary a great deal according to its type. For example, in a strand anneal for strip the actual furnace temperature may be several hundred degrees hotter than the metal ever gets because the strip travels fast enough to prevent overheating. The same sort of thing occurs in continuous furnaces of the belt or conveyor type used for tubing. On the other hand the batch or “bell” furnaces do not use such high “temperature heads”. All types of furnaces, however, must be calibrated after installation so that mill

operators will know what combinations of furnace load, temperature and time will produce the desired result for various metals and alloys.

Perhaps we should digress at this point to show the reasons for controlling grain size.

We have previously mentioned that finish tempers are controlled by giving a certain percentage of cold working on a soft material. There are, however, degrees of softness. A material with a small grain (say .010 mm.) is not as soft as one with a large grain (say .100 mm.). Perhaps it is too obvious to point out here that with a given degree of cold work we will obtain a harder temper from the material, which is not as soft in the first place. Therefore, to control temper we must control the degree of softness of the material we cold work to finish. In mill terminology we control the ready-finish grain size.

A second reason for control may be taken from the customer's viewpoint. If he wishes to do severe work on the material he must have very soft material (a large grain). On the other hand, if appearance is an essential item a small grain is indicated to avoid an "orange peel" or grainy appearance on any bent or stretched surfaces. This is particularly true if polishing or plating is done. In this instance the customer probably wants as soft a material as he can get for ease in working—and yet the grain must be fairly small. A compromise, therefore, is indicated and close control is necessary.

Previously we mentioned the amount of cold work affecting the annealing temperature; the greater the amount of cold work prior to annealing the lower the temperature at which softening takes place. It also varies from one metal to another so that Cupro-Nickel or Aluminum-Bronze anneals at several hundred degrees higher than copper, for example. Small amounts of some elements may have very powerful effects on annealing temperature; for example, silver-bearing copper has from 8 oz./ton up to 60 oz./ton of silver added. This is only .027% to .2% silver, yet annealing temperatures may be increased several hundred degrees.

Note that this also means that material will not

soften readily when soldered and will resist, without softening, higher operational temperatures. Conversely various other elements may occur as impurities, e.g. iron, tin, silicon, nickel and the like, which also raise annealing temperatures. Consequently, control of impurities is a necessary part of manufacturing techniques.

To sum up the simple annealing properties of simple alloys:

1. A certain definite recrystallization temperature is required for a given material.
2. This temperature is lowered by an increase in the amount of previous cold working.
3. The temperature is raised by the presence of other elements—accidental or otherwise.
4. The size of the final crystal may be controlled by the amount and time of heating.
  - a. Increase in temperature or increase in time increases grain size.
  - b. Decrease in temperature or decrease in time decreases grain size.

Thus far we have discussed only the simple annealing of cold worked materials to restore ductility for further working on our part or for further fabricating by our customers. There are other forms of heat treatment, however, which are related to particular types of alloys.

For example, there are a large number of alloys of aluminum, steel and some in copper, which are "precipitation hardened". That means we have added an element, or elements, which dissolve in the base metal at elevated temperatures, and will be retained in solution only if we cool suddenly to room temperature. If we then reheat to a lower temperature for a certain length of time, the elements will 'precipitate out'. In other words, a number of very fine particles of compound will not be dissolved any more and will be so placed in the crystal structure so as to produce a marked strengthening effect.

In copper alloys it will also increase the electrical conductivity from that in the unheat-treated state. Notable examples are Beryllium Copper (170, 172, 175),

Chromium Copper (184, 185), Zirconium Copper (150). (In Aluminum, those alloys containing both magnesium and silicon are the most common). Note that in brasses containing less than 64% copper we have a second phase, called beta. We can retain the beta at room temperature if we cool rapidly (water quench) from the formation temperature. However, it is not in our best interest to do so because beta brass is considerably harder than alpha brass and does not provide as good cold-working properties as all alpha brasses. This is not precipitation-hardening, however, but only the control of phases which will or will not be present after fast cooling. There is no reheating to 'precipitate out' the hardening constituent.

Another phenomena, as a result of cold working and annealing, is "preferred orientation"; which can occur with copper metals as well as aluminum alloys. With certain combinations of cold work and annealing the crystals are so aligned that elongation in one direction of the strip is different than in another. Its effects are seen in deep drawing so that a cup-shaped piece will have a wall higher in spots than others. These "ears" occur in copper as 4 in number at 90° to each other and 6 in number in brass with less than 64% copper. Both copper metals and aluminum may be ordered as "non-earring".

## CORROSION

Copper and copper-base alloys possess certain physical and chemical properties that make these metals highly corrosion resistant, a fact of unusual significance in the development of our industrial economy.

It is not our purpose to name the multitude of uses for which copper-base alloys are suitable and superior to other commercially obtainable metals, although some mention of the broader applications will be made from time to time. For the moment, however, our objective is to delve into some of the technical aspects that occasionally arise in the study of corrosion problems.

The reason it is frequently difficult to satisfy an inquiry, as to whether or not copper or its alloys can successfully withstand a corroding medium, is because of the very large number of factors which enter into the actual corrosion.

There are at least twelve factors affecting the service life of the metal under industrial conditions. These are:

- 1. Time of Exposure** — Obviously, the longer time of contact between the corrodent and the metal, the more chances for corrosion to take place. Designers may take this into account, so that a known corrosion rate may offer useful life in spite of eventual failure if left in service long enough.
- 2. Temperature**— There is a general rule in any chemical reaction that as the temperature increases the rate of reaction also increases, Frequently a rise of a relatively few degrees can greatly accelerate corrosion.
- 3. Concentration of Corroding Medium**— It is especially essential to have some idea as to the amount of the corroding agent present, since the corrosion rate will change with concentration, and not always as might be expected. A typical example is commercial concentrated sulphuric acid, which may be shipped in steel tank cars, but which is extremely corrosive to steel as a 10% acid solution.

**4. Oxygen —**

Oxygen is a cause of corrosion in itself, as well as being an accelerator of corrosion for other substances. As an example, sulphuric acid will not attack copper when oxygen is absent but, since this condition rarely occurs in industry, sulphuric acid can be considered an active corrodent. On the other hand, in the absence of oxygen, it will attack stainless steel.

**5. Movements —** The velocity with which the corroding medium passes by the metal surfaces greatly affects the rate at which corrosion may proceed. A typical example is Condenser Tube, where an increase in velocity may greatly increase the rate at which corrosion takes place.

**6. Purity —** Industrially speaking, it is impossible to be sure that substances are pure, and the presence of very small amounts of foreign materials can radically change the corroding rate. As examples, the presence of oxygen is largely responsible for the corrosiveness of many substances which are otherwise innocuous or the addition of small amounts of carbon dioxide to ordinary water produces serious corrosion on copper and finally, the addition of moisture to sulphur dioxide makes it corrosive to copper.

**7. Corroding Agents —** Obviously, it is necessary to know what corroding agent is in contact with the metal. Whether or not experience may be available to give a proper answer to expected life, will depend upon the type of corrodent.

**8. Static Stress —** Static stress, which is due to the loads imposed upon metal by water pressure, steam pressure, or due to structural design, can affect corrosion damages, as it may induce stress corrosion cracking among other things.

**9. Alternating Stress —** Alternating stresses are those which typically are found in springs which

are vibrating back and forth. The presence or absence of such alternations of stress are part of the background in determining expected service life.

**10. Galvanic Action (Electrolysis) —** This will be discussed in greater detail later.

**11. Metal involved —** As will be discussed later, it makes a great deal of difference as to whether the metal is inherently resistant to corrosion because of its position in the electromotive series or, whether it is capable of producing oxides or other insoluble compounds which will either retard or completely stop the corrosion. On the other hand, formation of highly soluble corrosion products usually means accelerated corrosion rates.

The type of crystal structure may also be important. Selective corrosion of certain phases can take place such as in the "beta" brasses or the "sigma" phase in stainless steel.

**12. Type of Attack —** Some corroding agents typically produce pitting instead of uniform corrosion. Obviously, under such circumstances, expected service life might be considerably shorter than if overall corrosion can take place.

#### CAUSES OF CORROSION

Corrosion is a complex process but which can, for our purposes, be broken down into three basic conditions:

1. Atmospheric
2. Water Solutions
3. Elevated Temperatures These will be discussed in more detail in the following:

**1. In the atmosphere** - of which most important factors are oxygen and water, plus carbon dioxide

for non-polluted air. In industrial or city environments there may be sulfur dioxide and other sulfur compounds; nitrogen oxides and ammonia to name a few. As a practical matter, copper and its alloys do not corrode in most atmospheres. Copper forms a greenish coating after a while, called "Patina", considered architecturally desirable. Other colors of browns and blacks may form if sulfur is present. There are many copper roofs still in service after several hundred years. Previous service life of copper metals is often the best way of deciding what to use.

**2. Corrosion in Water Solutions** - This is by far the most common form of corrosion and usually occurs in one of the following ways:

- (a) Galvanic Action
- (b) Replacement of one metal by another or by one metal and hydrogen
- (c) By an oxidation process

To further explain:

(a) Galvanic action occurs only in a conducting solution when two dissimilar metals are placed in it. A conducting solution usually means an acid, alkali or a compound of either is present. (Distilled or de-ionized water is not conducting). This allows an electromotive force to be established so that one metal is corroded. In Table I many common metals and alloys are listed. Materials close to each other will not corrode the other, such as zinc and aluminum alloys or copper alloys and nickel alloys. On the other hand, steel and copper results in corrosion of the steel. Of the two metals involved the one nearer the top of the list will be corroded. As an example, an iron coupling used to attach two lengths of copper pipe together will eventually result in the coupling corroding thru if the water is at all corrosive, such as one containing carbon dioxide.

## TABLE I GALVANIC SERIES

Corroded End (Anodic, or Least Noble)

Magnesium  
Magnesium Alloys  
Zinc  
Aluminum 1100  
Cadmium  
Aluminum 2017 ST  
Steel or Iron  
Cast Iron  
Chromium-Iron (Active)  
Ni-Resist  
18-8 Stainless (Active)  
18-8-3 Stainless (Active)  
Lead-Tin Solders  
Lead  
Tin  
Nickel (Active)  
Inconel (Active)  
Brasses  
Copper  
Bronzes  
Copper-Nickel Alloys  
Monel  
Silver Solder  
Nickel (Passive)  
Inconel (Passive)  
Chromium-Iron (Passive)  
18-8 Stainless (Passive)  
18-8-3 Stainless (Passive)  
Silver  
Graphite  
Gold  
Platinum

Protected End (Cathodic, or Most Noble)

(b) Chemical Replacement. When chemical compounds are dissolved in water, a phenomenon takes place called dissociation, wherein the atoms of one part of the compound will assume positive valence and the other portion will assume negative valence. As an example, when copper sulphate is dissolved in water, the copper has a valence of plus two, that is there are two positive charges, and the sulphate, which is composed of sulphur and oxygen, acts as an entity and has two minus charges. It is chemically written as Copper (Cu<sup>++</sup>) and Sulphate (SO<sub>4</sub><sup>--</sup>) These ions, with their positive and negative charges, explain many of the reactions which take place in water solutions. The mere fact that ionization takes place does not necessarily mean, however, that a chemical reaction will occur, because there are many factors which will affect the reaction.

Similarly, when acids are made into water solutions, dissociation takes place and in the case of sulphuric acid there are two hydrogen portions, each carrying a positive charge, and the sulphate again acts as an entity with two minus charges. This is written 2H<sup>+</sup> and SO<sub>4</sub><sup>--</sup>. The degree to which this ionization takes place determines, in a great measure, how strong the corrosive attack will be. Relatively weak acids which, however, have a strong tendency to dissociate, can cause rapid corrosion.

To determine some of the relative tendencies for metals to be corroded by acids which dissociate, Table II is useful, which is much similar in character to Table I, but provides additional information.

The metallic elements are listed by name and by their chemical symbol and also have a figure following each one of them which is in most cases a minus, but in some is plus. It will be noted that all of them are in reference to hydrogen, which is rated as zero. The figures represent the electrochemical voltage, which is established when compared to hydrogen in

normal solutions.

**TABLE II  
ELECTROMOTIVE SERIES**

The following are the approximate single potentials of metals toward solutions with normal metal ion concentration, based on the normal hydrogen electrode as zero:

NAME	SYMBOL	POTENTIAL
Lithium	Li	-2.96
Potassium	K	-2.92
Barium	Ba	-2.80
Sodium	Na	-2.71
Strontium	Sr	-2.70
Calcium	Ca	-2.50
Magnesium	Mg	-1.55
Manganese	Mn	-1.00
Zinc	Zn	-0.76
Chromium	Cr ++	-0.60
Chromium	Cr +++	-0.50
Iron	Fe	-0.44
Cadmium	Cd	-0.40
Cobalt	Co	-0.29
Nickel	Ni	-0.22
Tin	Sn	-0.14
Lead	Pb	-0.12
Iron	Fe +++	-0.05
Hydrogen	H	0.00
Antimony	Sb	+0.10
Bismuth	Bi	+0.20
Arsenic	As	+0.30
Copper	Cu	+0.35
Mercury	Hg	+0.80
Silver	Ag	+0.80
Gold	Au	+1.40

For the conditions under which the above table was determined, all metals above hydrogen are capable of displacing hydrogen from solutions containing hydrogen ion .i.e., they are soluble in acids.

Those below hydrogen are (usually) unable to displace hydrogen directly.

Those with minus signs are attacked by air-free acids. The hydrogen is evolved as a gas. As an

example, with iron and sulphuric acid a reaction takes place so that hydrogen is evolved and iron sulphate is formed.

It will be noted that copper is below hydrogen in this table. Copper will not evolve hydrogen when immersed in acids except at high concentration.

Table II also shows why gold and silver are not readily attacked by certain acids, that is, they are essentially noble”.

Complicating these statements above is the fact that certain acids are of so-called oxidizing character; that is to say, they act as if oxygen were present. This may completely change the action which might otherwise be expected from the position of the various metals in the electromotive series.

(c) Oxidation. Oxidation, chemically speaking, is the raising of the valence. If this power exists, then oxidation takes place even though there may not be any oxygen itself involved. Oxygen can also raise valence. Other substances such as sulphur or chlorine or sodium bichromate, and many others, have this same power to raise valence.

As we have said, valence is the number of charges carried on the ions when in solution and changing this number of positive charges, to let us say from one to two, or from two to three, would be an oxidation process.

There are some acids which not only will dissociate to form hydrogen ions, but also act as oxidizers at the same time, such as nitric acid. Another example is phosphoric acid which contains an appreciable percentage of iron. These compounds of iron, which are in such a state of valence as to be called ferric as contrasted with ferrous, are highly oxidizing in character. The combination of active acids in oxidizing agents is a very destructive one for many commercial metals.

Some other materials which are oxidizing in character and, therefore, corrosive to copper and its alloys are nitrates, chromates, chlorates, permanganates, and cupric (copper) and stannic (tin) compounds.

Oxidation is most evident in the case of heating metals for hot rolling sheer, strip or plate; hot piercing of tubes; hot extrusion of tube and rod. In this case

oxygen in the air reacts directly to form copper oxide on electrolytic tough-pitch copper or slight variations thereof while brasses, aluminum bronzes and copper-nickel alloys will also have some oxides of the added elements used to make the alloy.

**3. High Temperature Corrosion** — We mean higher than room temperature, for the most part, when we speak of this form of corrosion. In modern power plants, steam may be as hot as 1050°bf, which requires very special alloys to handle—and very special treatments to exclude various corrosive substances, including oxygen.

There are very definite limits to the temperatures to which copper metals may be exposed, partly because they lose strength and partly because of oxide formation which may waste away the base metal and hence reduce the thickness or section below a safe strength level.

Generally speaking 800°F. is maximum for high-strength alloys and 400°F. for electrolytic copper.

Other than oxygen there are various gases which attack copper metals at elevated temperatures, such as those containing sulfur, chlorine and the like. Scales or films may be formed which are loose and not adherent, and hence not protective to the metal.

In addition to these, molten salts may be corrosive as well as molten metals. Liquid tin, soft solders, and some silver solders are corrosive when in contact for a certain length of time because they form new metal alloys, which may not be strong and ductile, but rather weak and brittle.

Liquid mercury is a corrosive metal at room temperature.

## TYPES OF CORROSIVE ATTACK

In this portion will be covered the most common types of failures which occur with copper and its alloys. Most of the types of failures, however, may occur with other metals.

At the same time, the arrangement of the types of failure will indicate the manner in which the Research Department can identify the various types of corrosion that are encountered. Fortunately, the types of attack are usually typical enough so that they can be readily identified by the marks which they leave upon the metal. These characteristics, along with corrosion products which are usually left, serve as quite positive clues for identification of the trouble.

### **1. Erosion-Corrosion (Impingement) —**

This type of failure is most frequently encountered in condenser tubes, piping, or in such vessels as those where streams of liquid or gases emerge from an opening and hit upon the side wall, or within a tube where liquid turbulence occurs. The velocity or speed of the liquid which is required to cause failure of a given material will vary with composition of the metal and the composition of the liquid. The presence of entrained air bubbles, sand, paper pulp, or other solid particles will greatly accelerate the impingement failure, as well as contaminants of a chemical nature.

In condenser tubes, obstructions such as mollusk shells or debris will cause local failure by producing a hole through the tube wall, long before the rest of the metal fails.

The commonly accepted cause of failure by impingement is the inability of the metal to replace the thin film on the surface which is otherwise customarily present. There seems to be little or no relation between the hardness of the material and its ability to withstand erosion. We are not talking about resistance to wear which would be typical of pipe lines carrying large volumes of sand or other abrasives.

The alloys most resistant to impingement attack are the Cupro-Nickels (706 and 715),

which accounts for their widespread use as condenser tube material in warships and other marine installations where there is a combination of corrosion by salt water and erosion due to the velocity of that water.

Other important alloys are Aluminum Bronze (608 and 614) and Aluminum Brass (687), which are intermediate between Admiralty Metal (443, 444, 445) and Cupro-Nickel in their ability to resist erosion. There is a growing tendency to use these alloys in modern power stations where salt water is used for cooling.

Admiralty Metal, tonnage-wise, is most widely used since it offers a good resistance to many forms of water corrosion especially in the United States. In its inhibited form, the problem of dezincification is practically nil and is prevented by the use of arsenic, antimony or phosphorus in small amounts.

Copper (arsenical) (142) may be used in inland waters and Deoxidized Copper (122) for many air conditioning and similar condensers using fresh water.

**2. Stress Corrosion —** In the "brass" business, stress corrosion is commonly called "season cracking." The word season is defined here as "a period of time" and does not refer to any divisions of the calendar year. The requirements for season cracking to occur are three:

**(a) The alloy must be susceptible —** In a practical manner, it has been long accepted that those alloys of copper and zinc with less than 20% zinc are generally immune from season cracking. This would mean that Gilding, 95% (210), Commercial Bronze, 90% (220), and Red Brass, 85% (230), commercially will seldom season crack. Neither will the Cupro-Nickels, Phosphor Bronzes (505, 510, 521, 524) and copper.

There are exceptions to this which will be mentioned under corrosion—the second requirement.

**(b) Corrosion** — Some type of corrosive attack must be in operation in order to cause stress corrosion cracking. Even though the alloy is a susceptible one and even though the third requirement of stress is present, season cracking will not occur unless there is corrosion. However, the mere presence of air (containing oxygen and CO<sub>2</sub>) may be sufficient to provide this corrosion.

Ammonia is a particularly active corrodent in regard to season cracking and will be discussed in a little more detail further on. Steam may attack Silicon and Aluminum Bronzes.

**(c) Stress** —

The third requirement is stress. Usually this stress is internal and within the metal, but there are also occasions when such stress can be induced by loads imposed upon this metal due to service conditions. It must also be a tensile stress, not a compressive one.

Keeping these three requirements in mind, let us discuss further the factor of season cracking.

Under certain conditions, any metal can be made to season crack. Industrially, however, there are few failures occurring with our metals rich in copper.

The Silicon Bronzes with high silicon content, some Aluminum Bronzes, and High Zinc Brasses are generally susceptible to season cracking.

With metals containing more than 15-20% zinc, and with stress and a suitable corrodent present, season cracking can take place sooner or later. The actual time which may be required can vary from a few minutes to many years, depending upon the amount of stress and the corrosive attack of the surrounding medium.

Metals other than copper and its alloys, are also subject to stress corrosion cracking, and this includes stainless steel, nickel alloys, magnesium, aluminum, lead, etc. The corroding compounds causing season cracking

in these other materials may vary from those to which copper alloys are sensitive.

The amount of stress required to cause cracking depends upon the corrodent and with the alloy in question. The most frequent cause of stress corrosion cracking is the presence of internal stress due to differential cold working between one part of the metal and another part. For failure to occur, it is important to note that this stress must be in tension and not in compression.

While expert opinions differ, it seems pretty sure that most season cracking failures are due to ammonia in one form or another. It is quite probable that carbon dioxide, oxygen, and water vapor are also necessary for such action to take place. Ammonia can have many chemical forms, including organic compounds of the amine type, and certain plastics also have ammoniacal residues, so there are many potential places where ammonia can occur. There are other conditions also which may result in stress-corrosion cracking.

It is obvious that protective coatings can prevent the action of the corrodent from taking place, or which will slow it down radically, will greatly extend the expected service life of any part exposed to season cracking influences. There are certain lacquers offering a dense and adherent coating that will prevent season cracking even when exposed to strong ammonia fumes. Decorative platings will also slow down or entirely eliminate season cracking.

The obvious cure for season cracking is the use of some means to relieve the stresses which are inherently the cause. Either by the use of a relief anneal, that is, a temperature low enough to eliminate these stresses without softening, or a full anneal. Where the form is suitable, the use of proper straightening machines will reduce the stress below that level required for season cracking. Such protective measures are

taken by Revere on those products whenever applications conducive to season cracking are known beforehand.

An accepted test for season cracking is the mercurous nitrate test specified by A.S.T.M. It is important to note that there is no true correlation between the length of time required for cracking in this test and the expected service life. However, quick and sudden cracking in mercurous nitrate solutions is indicative of extreme susceptibility in service.

The path of cracks due to mercury attack is invariably intergranular, as in many service failures. The presence of ammonia can induce transgranular cracking with the intergranular type.

**3. Corrosion Fatigue**— Fatigue is sometimes erroneously known as “crystallization.” The reason for this erroneous term is the fact that most fatigue failures will show a bright crystalline type of fracture along with a very smooth section. Fatigue commonly occurs at stresses considerably below those otherwise required to break the material because a concentration of stress exists at some point due to either a notch, a corrosion pit, a sharp angle, or some other abrupt change in dimensions.

The fatigue resistance of our materials is quite good, but in common with all other metals can be lowered by the presence of active corroding agents. Most typical examples of failure by fatigue will be in shaftings, condenser tubes, springs, bellows and similar places where corrosion is active and vibration can occur from one cause or another. Corrosion fatigue in condenser tubes may be caused by pump pulsations or by harmonic motion set up by high velocity steam being emitted from the turbine and striking the tubes.

Identification of a corrosion fatigue failure under the microscope is usually by means of the crack which is typically across the crystals. Also,

there is found usually at the surface of the piece where the crack started, a corrosion pit which has served as a starting point.

**4. Dezincification**— Dezincification is a word peculiar to the brass industry and denotes a type of attack which is most prevalent in the brasses containing more than 15-20% zinc.

The Silicon Bronzes, the Cupro-Nickels, the Aluminum Bronzes, the Nickel Silvers, and the Phosphor Bronzes are not subject to dezincification.

The Aluminum Bronzes, however, are subject to a similar type of attack which is referred to as “dealuminification”, but if the structure is all “alpha” it will not occur.

Most frequently, dezincification takes place in acid solutions or others which are strongly conducting. The simplest explanation for the mechanism is that the copper-plus-zinc alloy is dissolved out of the metal and the copper is redeposited electrochemically. The zinc goes into solution and stays there or is precipitated as scale.

Two common types of dezincification occur. One is the plug type wherein corrosion pits are filled with redeposited copper. The second is called the “layer type”. Here the entire metal surface is thinned to a more or less uniform depth and the copper redeposits over the entire surface creating a layer.

The cure for dezincification is the use of inhibitors which are most effective in single phase alloys. In such duplex phase material as Naval Brass, Free Cutting Brass and Muntz Metal, the use of inhibitors does not entirely suppress dezincification but may retard it.

Dealuminification can take place in Aluminum Bronzes, as mentioned beforehand, and again is due largely to the presence of acid or conducting solutions. The mechanism is much similar in that copper is redeposited upon the original base metal. Under certain special conditions

Cupro-Nickel has been known to "denickleify" but it is not common, and does not occur in unpolluted salt water where much of the alloy is used.

5. **Pitting**— Pitting is mentioned as a type of corrosion because it is unusually destructive, since one pinhole can frequently ruin a tube, pipe or vessel. Some corroding agents typically seem to cause pitting and our alloys are no more prone or immune to such action than any other of the commercial metals. For example, Monel Metal and Stainless Steel are subject to pitting under certain conditions.

One of the worst actors with which copper alloys have to contend is carbon dioxide in natural waters. The type of attack is usually pitting and may be severe.

6. **Concentration Cells**— A concentration cell will leave a pit, and is in this respect a failure due to pitting. It is mentioned specifically, however, because concentration cells of one type or another are frequently encountered in service.

A most common cause of pitting is due to a difference in oxygen concentration at a particular point. This can be caused by barnacles or other attachments to the metal which prevent oxygen from reaching the surface. A concentration cell is thus set up where a difference in potential exists, and corrosion can actively take place. As a matter of fact, most concentration cell action is quite rapid and causes early failure.

Solutions containing mud or suspended solids may deposit coatings of them which will exclude oxygen. Gaskets, supports and other places which result in deficient oxygen will do the same thing. Alloys with their own oxide coatings as protective films are quite susceptible (aluminum alloys and stainless steel are examples).

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Copper is actually a very corrosion resistant metal considering the problem as a whole.

It is naturally resistant because it is cathodic to hydrogen, that is, it will not release hydrogen when it is attacked by most acids (see Table II).

There are exceptions to this as in the case of the strongly acting hydrochloric acid, which copper will not handle, and also to oxidizing compounds such as nitric acid, certain salts, as well as iodine and chlorine. Mercury strongly attacks copper and copper alloys aside from its season cracking characteristic. Ammonia, largely due to its highly soluble corrosion products, is also strongly corrosive, as are the cyanides.

Copper is widely used to resist corrosion in all sorts of atmospheres, as witnessed by the considerable tonnages which are used for air-conditioning equipment, for roofing, for pole line hardware, bolts and nuts, screws, screening, marine hardware, heat exchanger tubes and so on almost without end.

Copper and copper alloys are also resistant to attack by most types of water. As mentioned previously, those waters carrying carbon dioxide are the most difficult to handle, as are those containing acid mine water.

Copper is widely used as water tube for piping, not only in homes but in a wide variety of industrial uses to conduct water and water solutions.

The automotive industry is a large user of copper and its alloys, principally for radiators and heaters. Paper mills, chemical plants, power stations, oil refineries, and ships are all examples of uses of copper and its alloys as pipe or condenser tube.

Because of its high electrical conductivity, copper is the preferred material with the electrical industry for bus bar, commutator segments and various electrical devices and appliances.

The general resistance of Admiralty, Cupro-Nickel and Aluminum Bronze to such salt-containing solutions as sea water is very good, and these alloys are widely used in marine applications, including desalination plants for converting salt water to fresh.

The refrigeration and air-conditioning industries use large quantities of copper because of its resistance to

the refrigeration agents commonly used, and its ability to be joined by soldering or brazing without the need of highly corrosive fluxes which must later be removed by expensive cleaning procedures.

### **HANDLING CORROSION PROBLEMS**

Revere maintains a Research and Development Center which has on its staff, qualified engineers and scientists who are familiar with corrosion phenomena. It is their function to recognize various types of failures, relate them to the probable cause and then suggest a possible remedy. This may involve a suggestion that operating conditions need to be carefully checked and possibly changed or that a different alloy should do a better job.

Corrosion problems can be quite complex and are best handled by specialized technical people.

[40]

### **SPECIFICATIONS**

Revere products must obviously be made to certain standards, and equally obviously the customer must describe the product which he wishes to buy. We have previously briefly described several of the standards-writing agencies in connection with the discussion on tempers. More explanation seems in order, however.

The Copper Development Association serves as a technical and standards agency for producers of brass mill products (Rever's copper and brass business for one) and is supported financially by them. Among its various functions, it helps establish industry wide standards for alloy identification numbers, compositions of same, tolerances, physical properties, etc. These are published by CDA and form a valuable source of information in addition to their value as standards.

Among the specification writing agencies are the following:

- American Society for Testing and Materials (ASTM)

- American Society of Mechanical Engineers (ASME)

- Aeronautical Material Specifications of the Society

- of Automotive Engineers (AMS)

- American Welding Society (AWS)

- Federal specifications (Prefixes QQ-B-; QQ-C-;

- QQ-P-; QQ-R-; QQ-W- followed by a number

- and also prefixes WW-T- followed by a number)

- Military specifications (MIL followed by a letter

- and a number)

A cross index to these is published by CDA. In addition, there are a number of privately written specifications to cover special requirements of users such as General Electric Co., Western Electric Co., Westinghouse Electric Corporation, to name a few.

In the absence of any directions to the contrary, when a customer orders from us, we will use ASTM values for the product involved. This brings up the question of proper ordering descriptions, and the recommended procedure is to include the following:

[41]

## ORDERING INFORMATION

1. Quantity - pounds, feet, pieces, etc.
2. Copper Alloy Number - (name where applicable).
3. Product - such as sheet, strip, condenser plate, condenser tube, water tube, drainage tube, refrigeration tube, roofing sheet, etc.
4. Dimensions - width, thickness, etc. - OD and wall for tube - length. It is preferred to use decimals rather than gauge numbers.
5. How furnished - as straight lengths, dimension sheet, coils, spooled.
6. Temper - Generally speaking we prefer to use Tensile Strength or Rockwell Hardness for cold worked material and grain size for annealed, though there are exceptions due to how particular products are used. The commercial ranges appear in the governing ASTM specification.
7. Specification by issuing body, number and product.
8. Shipping date.

It may be necessary to add other bits of information such as:

Finish - especially if for highly polished products as vanity cases, etc.

Tolerances - if closer than commercial (which are always subject to mill acceptance) in regard to dimensions, including length, straightness, ovality of tubing and the like.

Especially important is product name in the case of such items as condenser tubes, water tube and several others, since the end use dictates certain dimensions, or tolerance or weight control which are different than another product of the same shape and alloy.

If it is not known how to order material because it has not been made before by Revere then samples of a previously, successfully used material should be submitted to the Metallurgical or Technical Service people for checking of properties. If a new product, a print of the part is preferred. For some situations a personal visit is in order, by one of the technically qualified people available at the Divisions, or the Research and Development Center.

## GLOSSARY OF TERMS

- ADMIRALTY (443) — 71% copper plus zinc with 1% tin; largely used for condenser tubes.
- ALLOY — a composition of two or more commercially pure metals.
- ALPHA BRASS — any brass containing more than approximately 64% copper which normally shows only Alpha crystals under the microscope.
- ALTERNATING STRESS — the cyclical change from tension to compression and back again in the metal. Example — reversal of spring deflections.
- ALUMINUM BRASS (687) REVALON® — a metal containing 77% copper, 21% zinc and 2% aluminum as its chief constituents.
- ALUMINUM SILICON BRONZE (642) — alloy consisting chiefly of copper with aluminum and silicon added to give it additional qualities of strength and hardness.
- AMORPHOUS — refers to absence of crystalline structure.
- ANNEAL — process of softening metals by subjection to moderate or high temperatures. The hardness of annealed metals *will* vary with the degree of anneal.
- ARCHITECTURAL BRONZE (385) — actually a special brass whose composition and properties render it suitable for extrusion into complicated shapes for architectural and industrial use.
- ASME — American Society of Mechanical Engineers — a nationally recognized professional group of engineers whose fundamental purpose is to exchange engineering information among its membership.
- ASTM — American Society for Testing and Materials — this is the foremost body of specification writers in the world.
- BERYLLIUM COPPER (170, 172, 175) — a copper-base alloy whose chief addition is beryllium. The principal properties of the alloy are great hardness, resistance to fatigue failure and an ability to be tempered.

BETA BRASS — a copper zinc phase which forms when zinc is between about 36 and 50%. Very ductile at hot working temperatures. Contrast with “alpha” phase or gamma” etc.

BRASS — any alloy of copper with zinc as the principal alloying agent, with or without small quantities of some other metals.

BRINNELL — a test used for measuring the hardness of a specimen wherein a steel ball of standard diameter is pressed into the test sample under a given load.

“B” SCALE — (Rockwell) — a specific scale of numbers used in the Rockwell testing of specimens whenever a 1/16” ball with 100 Kg load is applied.

B. & S. GAUGE — The Brown and Sharpe or American Wire Gauge — the diameters of wires having successive numbers in this gauge are in the ratio of 1.123 to 1. also used for strip or sheet.

CARTRIDGE BRASS (260) — an alloy composed of 70% copper, 30% zinc providing combined strength ductility and resistance to corrosion. Is well — suited to deep drawing of all kinds.

CATALYSIS — acceleration of a chemical reaction by a substance (catalytic agent) which itself appears to remain unchanged.

CATHODE — the negative electrode of a cell.

COLD DRAWN — a term used to define the process of pulling a material through a set of dies designed to reduce the cross — sectional area of the metal at essentially room temperature — for tube, rod and wire.

COLD ROLLED — the reduction in gauge of metal by rolling at room temperatures — for strip, sheet and rolled bar.

COLD WORKING — a general term used to describe the variety of processes used to

change the form of metals well below the softening temperature.

COMMERCIAL BRONZE (220) — an alloy containing 90% copper, 10% zinc; so called because of its bronze Color.

COMMERCIAL TOLERANCES — the “plus” and/or “minus” allowances that are acceptable on a specified dimension.

CONCENTRATION CELL — an electrolytic cell caused by concentration differences in the electrolyte.

CONDENSER TUBE (Also heat exchanger tube) — tube manufactured to special requirements as to straightness, tolerances, finish, temper and freedom from physical defects.

CORRODING MEDIUM — the chemical substance that corrodes.

CRYSTAL — a solid assembly of atoms, regularly arranged in three dimensional space.

CUPRO-NICKEL (See 700 Series.) — Several copper — nickel alloy compositions especially resistant to corrosion by salt water.

DEALUMINIFICATION — form of corrosion applying to Aluminum Bronzes of multi — phase crystal structure. (See Dezincification)

DEOXIDIZED — a term applied to any metal or alloy to indicate its having been treated to remove Oxygen. It is specially applied to copper and refers to removal of oxygen by means of phosphorus or other strong deoxidizing agents.

DEZINCIFICATION — a form of corrosion of brass characterized by solution followed by deposition of the copper back on the brass.

DISSOCIATION — breaking up of molecules into ions.

DRAWING — a process used to pull rod, tube, or wire through a set of dies for the purpose of reducing the cross — sectional area, hardening the metal, or changing its shape.

DUCTILITY — the inherent property of a metal denoting its ability to be cold or hot worked.

ELASTIC LIMIT — the unit stress to which metal can be put without permanent deformation.

ELECTROLYSIS — the decomposition of metals by means of an electric current.

ELECTROLYTIC COPPER — copper that has been refined by electrolytic deposition. Used for manufacture of tough pitch copper and copper alloys.

ELECTROLYTIC TOUGH PITCH COPPER — the remelted electrolytic copper containing about .03% oxygen comprising the bulk of copper” products.

ELECTROMOTIVE SERIES — a series in which the metals are arranged according to their normal electrode potentials.

ELONGATION — the stretch of metal under a tensile stress. The percentage of elongation is a measure of the ductility of metals.

EROSION-CORROSION — dual action taking place upon metal exposure to corrosive fluids which result in local perforation and due also to excessive velocity or turbulence.

EXTRUSION — the pushing of metal, usually at high temperature, through a die to form various shapes.

FATIGUE — the failure of metals by repeated or alternate stresses which are lower than static stresses which cause breakage.

FORGING ROD (377) — metal fabricated to rod or shape which will be later cut up, preheated and shaped while hot by the blow of a hammer or in a die.

FREE-MACHINING — ability to be cut easily by a cutting tool. Leaded brasses and tellurium copper exhibit this quality.

“F” SCALE — (Rockwell) — a specific scale of numbers adapted in the Rockwell test for measuring the surface hardness of a metal by use of a 1/16” steel ball with a 60 Kg load. (See “B” Scale.)

FULL HARD — the temper of metal cold rolled 4 B. &

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S. numbers or approximately 37%.

GALVANIC ACTION — a type of corrosion wherein decomposition of a metal takes place by means of an electric current that is set up whenever two dissimilar metals are in contact with each other in a conducting solution.

GAUGE — 1) a measure of the thickness of the metal, 2) an instrument used to measure the dimensions.

GILDING METAL (210) — a copper — zinc alloy containing 95% copper, 5% zinc. It is used chiefly on the basis of its color.

GRAIN BOUNDARIES...the boundaries between individual crystals or grains in metals.

GRAIN GROWTH — an increase in the grain size of metal.

GRAIN SIZE — the size of grains or crystals in metal, usually referred to in terms of average or mean diameter and expressed in millimeters, e.g., .010 mm is very small and .200 mm is very large.

HARDNESS — same as Temper.

HERCULOY (655) — a name applied to Revere Silicon Bronze. Its outstanding characteristics are high strength and resistance to corrosion.

HOT ROLLING — a process of fabrication used to reduce the cross — sectional area of metal at a temperature above the softening Point — usually above 1000°F for copper metals.

HOT WORKED — a term describing a metal that has been processed at a temperature above the softening point.

INTERNAL STRESS — the load per unit area developed inside a body by cold working or deformation.

ION — an electrically charged atom or radicle whose migration effects the transportation of electricity through electrolytes and occasionally through gases. Positively charged Ions are known as “Cations” and negatively charged Ions are known as ‘Anions”.

IONIZATION — the production of Ions from molecules such as Salts, etc.

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LEADED BRASSES — a special group of copper-zinc alloys that contain small amounts of lead which imparts free-machining properties to the metal. (See alloys in 300 series.)

MERCUROUS NITRATE TEST — an accelerated corrosion test whereby the use of mercury salts determines the presence of applied or residual stresses or their combination, which might bring about the failure of the metal in service or storage through 'season cracking'.

MIXTURE — a term used to denote an alloy or composition.

MOLECULE — a combination of two or more atoms.

MONEL METAL — a 66% nickel-copper alloy.

MUNTZ METAL (280) — a copper-zinc alloy having 60% copper content.

NAVAL BRASS (464) — a 60% copper-zinc alloy also containing 3/4% tin.

NICKEL SILVER — a name given to a group of copper-zinc nickel alloys which produce a metal of usually white color. (See 700 series.)

NONFERROUS — a term applied to metallic alloys not composed mainly of iron.

NON-OXIDIZING — a term used to describe resistance to oxidation.

OFHC\* — a combination of letters meaning "Oxygen Free High Conductivity." \*A registered trademark of American Metal Climax, Inc. for their oxygen free copper.

ORANGE PEEL — a rough surface defect obtained on cold working brass that resembles orange peel.

PHOSPHOR BRONZE — copper-tin alloys deoxidized by phosphorus — highly useful as material for springs. (See 500 series.)

PHOSPHOR DEOXIDIZED COPPER (U0 & 122) — copper that has been deoxidized with phosphorus.

PIERCING — an initial mill operation used in making seamless tubes by means of rolling a pre-heated billet in a Mannesmann-type mill.

PRECIPITATION HARDENING — this term is often referred to as "accelerated age hardening," and it is a process usually involving two heat treatment operations. The metal is heated to a high enough temperature to put elements into solution in more or less equilibrium. It is then quenched, trapping these elements in this state. A further heating to moderate temperatures will allow hard particles to precipitate from the solution throughout the crystalline structure. These particles interfere with the movement within the crystal and so impart hardness and strength. Beryllium Copper (170), Chrome Copper (182) and Zirconium Copper (150) are examples, as are many aluminum alloys.

PREFERRED ORIENTATION — a term describing a condition within the metal whereby the crystals are not arranged irregularly or "at random" but have a preferred or directional orientation.

READY-FINISH ANNEAL — a mill term referring to the anneal before the final cold working process.

RECRYSTALLIZATION — the transformation taking place in grain structure of cold worked metals during the process of annealing.

RED BRASS (230) — a copper-zinc alloy having an 85% copper content.

ROCKWELL — a term used to describe a hardness test reading on metal that was made by testing equipment called the "Rockwell Hardness Tester."

ROLLING — a general term applied to various processes which work the metal by means of rolling between cylindrical or shaped rolls.

ROMAN BRONZE — a copper-zinc alloy having a small quantity of tin. (See 464A.)

S.A.E. — Society of Automotive Engineers.

SCELERSCOPE — a device used for testing hardness of metals wherein a small hammer is dropped onto the sample from a fixed height and the hardness determined by the height of the

rebound of the hammer. Especially useful for checking rolls for strip or other rolling.

SEASON CRACKING — a term describing the failure taking place on metal possessing excessive internal or external stresses when in contact with a certain corroding atmosphere. This failure, which is seen as cracks, may take place after a few days, weeks or even longer.

SINGLE PHASE ALLOYS — alloys containing only one phase. e.g., cartridge brass.

SLIP-PLANES — planes in the metal of relatively easy slip or deformation.

SPECTROSCOPE — an instrument used for analyzing the spectra of rays emitted by luminous bodies, and hence the composition of an alloy or substance.

STAMPING — a process used to shape various articles by means of a die and a punch.

STATIC-STRESS — a steady force exerted in distinction to cyclic stresses.

STRAIGHTENING MACHINES — processing equipment used for taking out the bends and kinks in tube, rod and wire.

STRESS CORROSION — same as “season cracking.”

SUPERFICIAL ROCKWELL — using the 30T or 15T scales, which are lighter penetrating loads than for “B” & “F”, and are more suitable to testing of light gauge and/or annealed materials (see Rockwell).

TELLURIDE — a compound of tellurium.

TELLURIUM COPPER — copper containing a small amount of tellurium for purpose of improving machinability.

TEMPER — the condition of a metal or alloy determining its physical properties as produced by the mechanical and thermal treatments it has received.

TENSILE STRENGTH — the maximum breaking load per unit of original cross-section areas when tested in tension.

VALENCE — the number of ions that will combine with a given ion to form a molecule.

YIELD STRENGTH — as applied to nonferrous alloys, yield strength is an empirical value determined by the stress which will produce a certain amount of elongation, usually below the point of permanent deformation. (See ASTM E-8 for definitions and test methods).