WELDING OF COPPER AND COPPER ALLOYS : SOME ASPECT ON QUALITY

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INTRODUCTION

Copper and Copper alloys are used for their electrical and thermal conductivity, corrosion and oxidation resistance and distinctive aesthetic appearance. Copper is widely used for electrical conductors and for manufacture of electrical equipment. They are also used in reaction pressure vessels, evaporators, distillation columns, heat exchangers and for components in process industries like chemical, petrochemical, fertilizer, etc.

There are three basic grades of copper available commercially: oxygen-free, tough-pitch and phosphorous deoxidized copper. Oxygen-free Copper (Grade 1) contains a maximum of 5 ppm oxygen and a maximum of 0.01 % total of other elements. Silver may be added to oxygen-free copper to increase the elevated temperature strength without changing the electrical conductivity. The addition of silver prevents appreciable softening of cold-worked copper during short-term elevated temperature exposure.

Oxygen-bearing coppers includes the electrolytic tough-pitch grades and fire-refined grades. Impurities and residual oxygen may cause porosity and other discontinuities when these coppers are welded or brazed. A copper-cuprous oxide eutectic is distributed as globules throughout wrought form of oxygen-bearing copper and it makes the copper susceptible to embrittlement when heated in the presence of hydrogen. Hydrogen diffuses rapidly into the hot metal, reduces the oxides and forms steam at the grain boundaries. The metal will rupture when stressed.

When oxygen-bearing copper are heated to high temperatures, the copper oxide tends to concentrate in the grain boundaries causing major reduction in strength and ductility. Fusion welding of oxygen bearing copper for structural applications is not recommended. Embrittlement will be less severe with a rapid solid-state welding process such as friction welding. Appropriate silver brazing and soft soldering can be successfully used to join oxygen-bearing copper.

Phosphorus-deoxidised copper has 0.004 to 0.065 % residual phosphorous. Phosphorous-deoxidised grade is the standard material for general constructional work.

The most important alloys of copper are :

- Brass: Copper and Zinc
- Bronze: Copper and Tin
- Aluminium-bronze : Copper and Aluminium
- Silicon-bronze : Copper and Silicon
- Copper—Beryllium
- Copper—Nickel.

WELDING OF COPPER ALLOYS

The physical properties of copper alloys and the reaction of the molten metal with gases assume great significance in developing a suitable welding procedure. Table 1 shows physical properties of typical wrought copper alloys. The methods employed to reduce or compensate for heat losses from weld zone due to high thermal conductivity are:

- Covering or backing the work with an insulating material such as asbestos sheet or fire-brick.

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- Preheating both the fusion zone and considerable adjoining area.
- A more intense source of heat for welding can be used.

preheat temperature for a given application depends upon the welding process, the alloy being welded, the base metal thickness and to some extent the overall mass of the weldment. Thin sections or high energy

Table 1: Physical Properties of Typical Wrought Copper Alloys.

Alloy	Melting Range (°C)	Coefficient of Thermal Expansion at 20-300°C (µm/m.K)	Thermal Conductivity at 20°C (W/m.K)	Electrical Conductivity (%IACS)
Oxygen-free copper	1066-1088	17.6	370	101
Beryllium-copper	866-982	17.8	107-130	22
Commercial bronze	1021-1043	18.4	188	44
Red brass	988-1027	18.7	159	37
Cartridge brass	916-955	20.0	121	28
Phosphor bronze	955-1049	17.8	69	15
Aluminium bronze	1041-1046	16.2	67	14
High-silicon bronze	971-1027	18.0	36	7
Manganese bronze	866-888	21.2	105	24
Copper-nickel, 10%	1099-1149	17.1	38	9
Copper-nickel, 30%	1171-1238	16.2	29	4.6
Nickel-silver, 65-15	1071-1110	16.2	33	6

High thermal expansion of copper is responsible for high shrinkage stresses, which can be serious leading

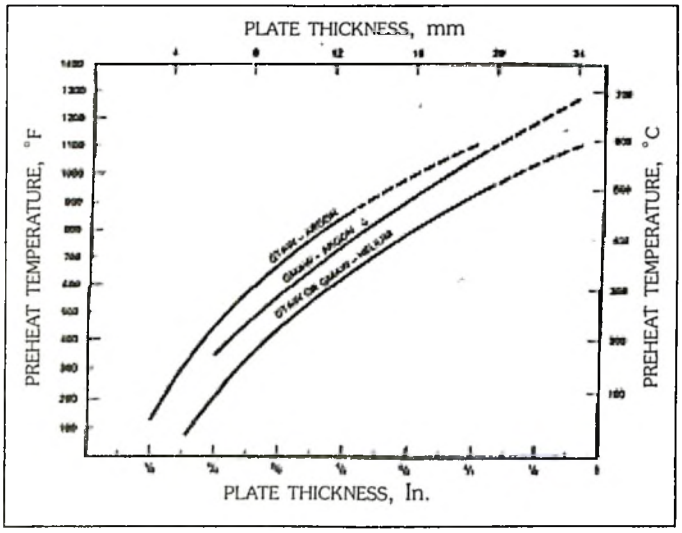

Fig. 1. Effect of Process, Shielding gas and Metal Thickness on Preheat requirements for welding Copper

to cracking at temperatures above 250°C (hot shortness) as the tensile strength is low. Preheating the entire component to an even temperature of between 200°C and 600°C should be taken. Selection of welding processes, such as EBW and LBW, generally require less preheat than the thick sections or low-energy welding processes. The use of GMAW process normally requires lower preheat than GTAW or OFW. When welding conditions are similar, copper requires higher preheat temperatures than copper alloys because of high thermal conductivity. Aluminium-bronze and copper-nickel alloys should not be preheated. Effect of process, shielding gas and metal thickness on preheat temperature requirement for welding copper is shown in Fig. 1. After welding the weld zone should be peened while it is at dull red heat. Refined grain structure can be obtained and this will cause increase in tensile strength.

WELDING PROCESS

The preferred welding processes are GMAW and GTAW processes since they provide a highly concentrated source of heat. Oxygen-acetylene can be used but is slow and inefficient. The high electrical conductivity of copper preclude the use of resistance welding except for those alloys with conductivity less than about 30% of the pure copper. For example, all resistance welding techniques can be used for phosphor-bronze, since the conductivity of the alloy is quite low.

FILLER METAL

Filler metal for welding copper usually contains phosphorus as a deoxidizer. Table 2 lists some typical filler metal types, which are covered by AWS A5.5-84 "Specification for Covered Copper and Copper Alloy Arc Welding Electrodes" and AWS A5.7 -84 "Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes".

POSTWELD HEAT TREATMENT

A range of other metallurgical problems can be encountered during welding of copper and its alloys, and although not difficult to weld, specific procedures must be followed. Some alloys rely on work hardening or precipitation hardening for their strength, and are therefore likely to suffer a reduction in the strength in the HAZ. To restore full properties in precipitation hardened alloys complete heat treatment after welding is recommended, but a suitable filler metal that will

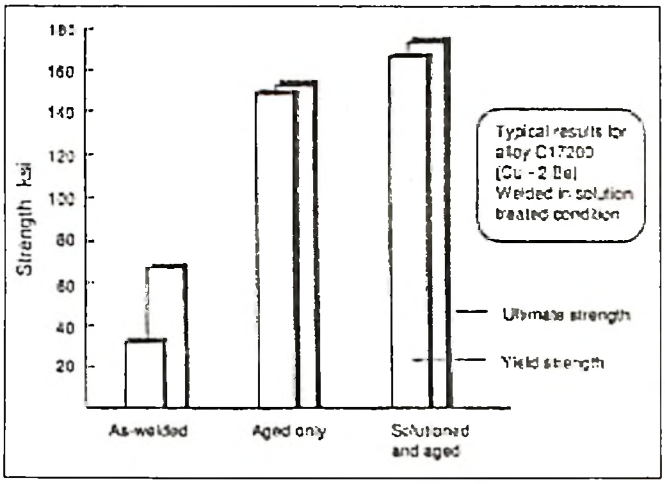

Fig. 2. The effect of postweld heat-treatment on the strength of welds in a precipitation hardening copper-beryllium

Table 2. Filler Metals for Fusion Welding Copper Alloys

AWS Classification		Common Name	Base Metal Application
Covered Electrode	**Bare Wire**		
ECu	ERCu	Copper	Copper
ECuSi	ERCuSi-A	Silicon bronze	Silicon bronzes, brasses
ECuSn-A	ERCuSn-A	Phosphor bronze	Phosphor bronzes, brasses
ECuSn-C	ERCuSn-A	Phosphor bronze	Phosphor bronzes, brasses
ECuNi	ERCuNi	Copper-nickel	Copper-nickel alloys
ECuAl-A2	ERCuAl-A2	Aluminium bronze	Aluminium bronzes, brasses silicon bronzes, manganese bronzes
ECuAl-B	ERCuAl-A3	Aluminium Bronze	Aluminium bronzes
ECuNiAl	ERCuNiAl	---	Nickel-Aluminium bronzes
ECuMnNiAl	ERCuMnNiAl	---	Manganese-Nickel-Aluminium bronzes
---	RBCuZn-A	Naval brass	Brasses, copper
---	RBCuZn-B	Low-fuming brass	Brasses, Manganese bronzes
---	RBCuZn-C	Low-fuming brass	Brasses, Manganese bronzes

respond to the heat treatment must be employed. Welding in the precipitation hardened condition is also likely to cause cracking in the HAZ and is not standard practice. As an example, beryllium-copper can be welded using beryllium alloyed filler metal followed by a complete solution treatment and aging. If the weld heat input is not excessive the HAZ will not over-age and good weld properties can be obtained by just a postweld aging omitting the solution treatment. Fig. 2 shows that proper heat treatment resulted in more than double the strength after welding.

SHIELDING

Alloys containing highly oxidisable elements, such as beryllium and aluminum, form oxides, which can be troublesome in welding. The metal in the vicinity of the weld must be maintained clean before and during welding. Good shielding of the arc is necessary to prevent the formation of oxides while welding. If the GTAW process is used, alternating current may be preferred because of the cleaning action during the electrode positive cycle. The aluminum oxide that forms on the surface of aluminum-bronze and gives its unique corrosion properties must be removed mechanically prior to welding.

Argon, helium or mixture of the two are used as shielding gases for GTAW, GMAW, etc. In general, oxygen is used when manually welding material that is either 3.3 mm thick or has low thermal conductivity, or both. Helium or mixture of 75% helium - 25% argon is recommended for machine welding of thin sections or alloys having high thermal conductivity.

VAPORISATION

In addition to oxidation, vaporization of alloy elements may cause problems. The boiling point of zinc 1663°F (906°C) is sufficiently low and during welding zinc vaporizes causing porosity, fuming, and of course reduction of the zinc content. Procedures for welding brass, particularly the high zinc brasses, must be designed to reduce zinc fuming by control of heat input, directing the arc onto the weld pool and filler metal rather than the parent metal, and by choice of consumables. Matching compositions are not available because the zinc would be lost, so phosphor bronze or aluminum bronze is used. Zinc losses can be reduced by adding silicon to the filler wire. The silicon in the filler will form silicon dioxide film on the surface of the weld pool, thereby reducing the volatization of zinc.

HOT CRACKING

The other major problem in welding copper alloys is hot cracking. A study of phase diagrams of the specific elements involved may, in some cases, give a clue as to the likely hot crack susceptibility. The copper-nickel diagram, for example, shows quite a wide solidification range, and copper-nickel alloys become

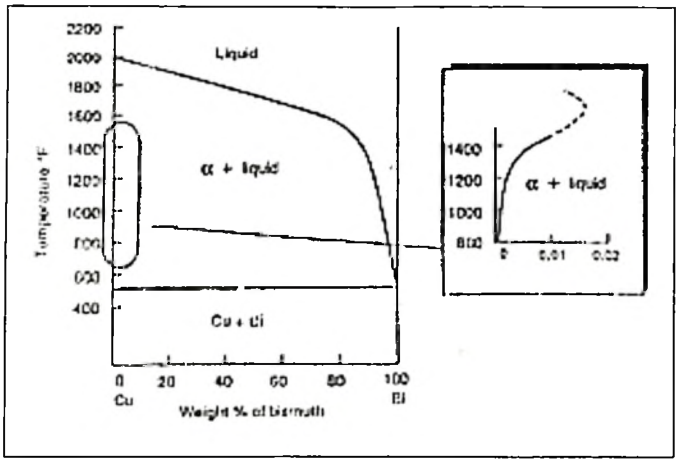

Fig. 3. Part of the copper-bismuth phase diagram showing the limited solubility of bismuth in copper and presence of liquid to very low temperature

highly susceptible to hot cracking during welding if impurity elements such as sulphur, lead, phosphorus, and bismuth are present. The copper-bismuth phase diagram shown in Fig. 3 demonstrates dramatically how even small quantities of bismuth can cause the retention of liquid phases down to low temperatures and result in a high susceptibility to hot cracking. Copper-nickel alloys should be carefully cleaned before welding to ensure no contamination with these elements takes place. Lead is deliberately used in some machining alloys but these should not be welded.

Two phase brass with 40% zinc is less susceptible to hot cracking than the single phase alloy. The same is true for the aluminum bronzes. The duplex structure found in the 9 - 15% aluminum alloy is essentially free of hot cracking when welded whereas the single phase 4 - 8% aluminum alloy is susceptible.

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