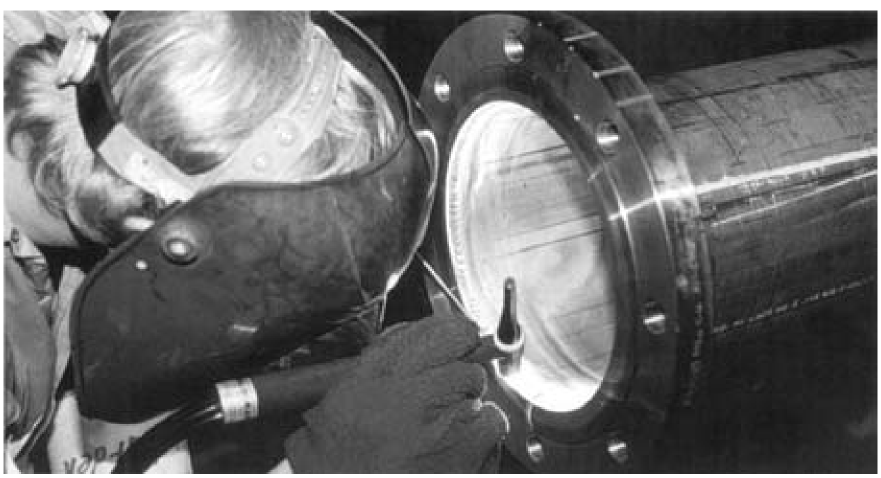
Copper-nickel FABRICATION

Handling | Welding | Properties
Resistance to corrosion and biofouling
Important applications



NiDI
Nickel Development Institute

Copper Development Association

CDA
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Introduction

Copper-nickel alloys have a remarkable combination of good resistance to both corrosion and biofouling in seawater. As they are also readily welded and fabricated, they are an obvious choice for pipe systems, heat exchangers, boat hulls and other structures engineered for marine use.

Copper-nickels have been specified for seawater use for over 50 years; they are the materials of first choice for seawater pipework and condenser service for many of the world's navies and merchant ships. They are used in desalination, power plants and offshore fire water systems, and for the sheathed protection of oil and gas platform legs and risers. In all such applications, their durability is proven. Fabrication of copper-nickels is not difficult, although a higher degree of cleanliness is required than for steel. They are ductile and easily formed. Their machinability is similar to that of aluminium bronzes, phosphor bronzes and other copper alloys that do not have special free-cutting additions. Copper-nickels can be welded by most standard processes.

The core of this book is welding and fabrication. General engineering properties, corrosion and biofouling resistance and applications are included only where they influence decisions on fabrication. It provides an informed understanding of the two primary copper-nickel alloys, to allow good fabrication and operation.

1999

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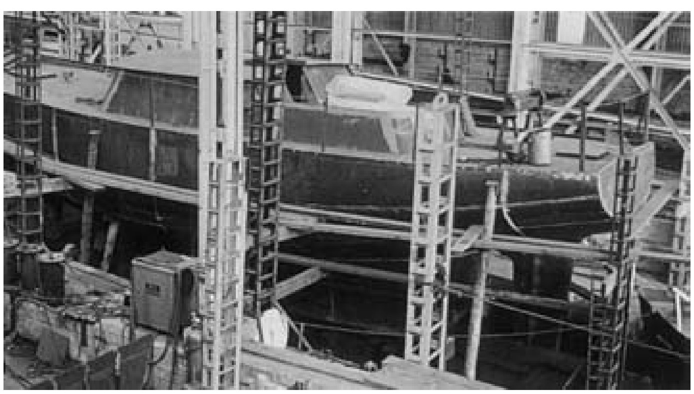

Hull construction of the *Sieglinde* Marie using – 6-mm-thick 90-10 copper-nickel plate

The alloys


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There are two main grades of copper-nickel alloy used in marine service – 90-10 (10% nickel) and 70-30 (30% nickel). The 70-30 alloy is stronger and has greater resistance to seawater flow; but 90-10 will provide good service for most applications – and being less expensive tends to be more widely used. Both alloys contain small but important additions of iron and manganese which have been chosen to provide the best combination of resistance to flowing sea water and to overall corrosion.

Standards
Table 1 gives some of the more common international designations for both alloys.

Table I Designations in standards for 90-10 and 70-30 alloys

Alloy	UNS	ISO	CEN
90Cu-10Ni	C70600	CuNi10Fe1Mn	CW352H
70Cu-30Ni	C71500	CuNi30Fe1Mn	CW354H

Composition
The chemical composition ranges for the two alloys vary among the different standards. If the product is to be welded subsequently, the ranges should preferably be within the limits given in Table 2. The maximum limits for some specific impurities are tightened because of their effects on hot ductility, and thus hot workability and weldability. These same detrimental elements can arise from external contamination and so precautions are necessary when the alloys are handled during forming and welding.

Mechanical and physical properties
Copper-nickels are stronger than copper but lower in strength than steels. Their ductility, toughness and formability are all excellent. They do not embrittle at low temperatures.

Table 3, opposite, gives typical annealed mechanical properties for copper-nickel plate; strength can be increased by cold working but not by heat treatment. Heat

Table 2 Typical chemical composition ranges of 90-10 and 70-30 alloys for welding applications

Alloy mass %	Cu	Ni	Fe	Mn	Zn	C	Pb	S	P	**
90-10	Rem*	9-11	1-2	0.5-1	0.5	0.05	0.02	0.02	0.02	0.1
70-30	Rem*	29-33	0.4-1	0.5-1.5	0.5	0.05	0.02	0.02	0.02	0.1

Single figures are maxima
*** Remainder**
**** Total other impurities**

The alloys

exchanger tubing is normally produced and ordered in the light drawn rather than annealed condition. For design purposes, precise values should be taken from relevant international standards based on product form and size.

Table 4 compares various physical properties with those of steel. The 70-30 alloy is essentially non-magnetic and has a magnetic permeability very close to unity. The 90-10 alloy has a higher iron content and can have a permeability between 1.01 and in excess of 1.2 depending on the final heat treatment condition. A fast cool from the solution heat treatment temperature is required to achieve a low permeability.

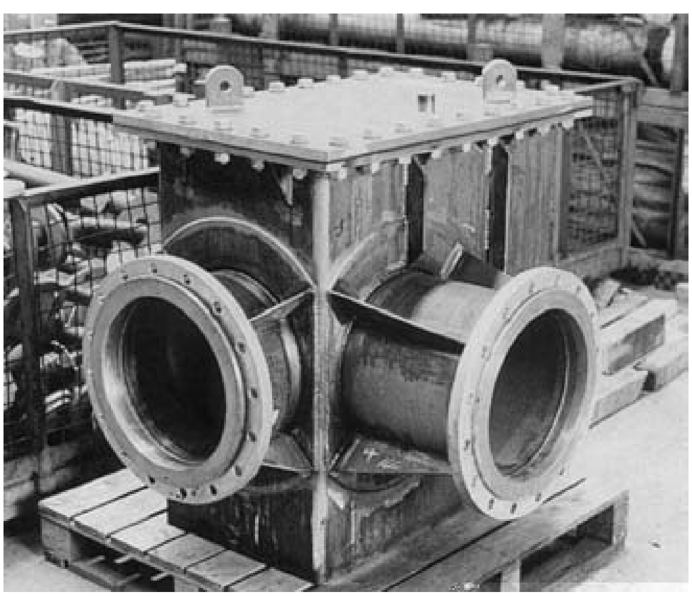
Table 3 Typical mechanical properties of annealed copper-nickel sheet and plate (taken from EN 1652:1997)

Alloy	0.2% Proof strength min N/mM^2*	Tensile strength min N/mM^2*	Elongation min %	Hardness HV
90-10	100	300	30	90
70-30	120	350	35	100

* 1 N/mm^2 is equivalent to 145psi

Table 4 Typical physical properties of copper-nickels and steel

	Units	90-10	70-30	Steel
Density	kg/dm^3	8.90	8.95	7.85
Melting points	°C	1100-1145	1170-1240	1460-1490
Specific heat	J/kgK	377	377	485
Thermal conductivity	W/mK	50	29	50
Coefficient of linear expansion 10-300°C	10^{-6}/K	17	16	12
Electrical resistivity	microhm/cm	19	34	30
Modulus of elasticity	GPa	135	152	210
Modulus of rigidity	GPa	50	56	81



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General handling

The precautions required for handling copper-nickels will be familiar to any fabricator who routinely handles materials like stainless steels and aluminium alloys, but may be new to those used to dealing with only carbon steels.

Cleanliness is paramount: contamination can cause cracking and porosity during heat treatment, or welding and may affect the corrosion resistance of the alloy. Ideally, fabrication should be done in an area devoted solely to copper-nickel alloys. Where this is impracticable, the standard of care of the material should be well above that necessary for carbon steels.

- Sheets should remain in their packing until needed and should be separated – normally by protective material – to avoid abrasion.
- Plates and sheets are best stored vertically in covered racks.
- Walking over sheets should be avoided.
- Plastic film may be interposed between the sheet and rolls when roll forming.
- Grease and paint should be kept away from the surface, particularly near edges of weld preparations; all traces of marking crayons must be removed before making a joint.
- Stainless steel brushes should be used, and tools such as grinding discs should not be interchanged between copper-nickel and other materials.

Cutting and machining

Most normal cutting processes – shearing, abrasive disc cutting, plasma arc, etc – are acceptable for copper-nickel. High-speed abrasive wheels work well for bevelling edges and trimming material.

The oxyacetylene process is ineffective in cutting these alloys, but the plasma-arc process gives excellent results. Band saws or shears may be used for cutting, but allowance made for their relative softness and ductility.

Although copper-nickels are not as readily machined as free cutting materials, they are not difficult to machine: they can be ranked with aluminium bronze and phosphor bronze alloys. They are much easier to machine than, say, stainless steels and other alloys which work-harden rapidly. More details and recommended speeds and oils are detailed in *Machining Brass, Copper and Its Alloys*, CDA Publication TN 44 (see Bibliography, page 27).

Forming

Copper-nickels can be hot or cold formed, although cold working is preferred – with an inter-stage anneal often necessary when the cold work exceeds about 40-50% of the total. A 20% cold reduction approximately halves the as-annealed elongation and doubles the proof strength.

Tubes can be bent by normal copper bending methods including bending machines. Care must be taken to get smooth bends and avoid wrinkling, because liquid turbulence in service can lead to impingement attack. Bends with radii greater than three times the diameter are usually acceptable. But with tubes of less than 80mm nominal diameter, a tube bend radius of twice the tube diameter can be produced. Smaller radii require prefabricated bends.

When tubes are filled before bending, non-carbonaceous filler materials – e.g., dry, oil-free silica sand – are preferred wherever possible and should be completely removed afterwards. Lubricating oil and filler residues must be

General handling

removed before annealing to prevent formation of carbonaceous films that may reduce the corrosion resistance in service.

Hot working copper-nickels can lead to hot cracking and should be avoided or attempted only with advice from a supplier. The recommended temperature ranges are:

- 90-10 850-950°C
- 70-30 925-1025°C.

Care must be taken below 750°C since low ductility may develop. An anneal after hot working is normally unnecessary.

Hot pipe bending is possible but not generally recommended; heating should be uniform over the whole circumference. When required, the pipe should be filled with dried, oil-free silica sand with no carbonaceous material. Bending should be done in one movement and jerking avoided. After bending, the filler must be removed completely (washing, degreasing and pickling).

Heat treatment
The work piece should be clean and free from any contamination before and during heating. Copper-nickels can embrittle if heated in the presence of contaminants like sulphur, phosphorus, lead and other low melting point metals. Sources of contamination include paints, marking crayons, lubricating grease and fluids, and fuels. Fuels used must be low in sulphur; normally, fuel oils containing less than 0.5% by weight of sulphur are satisfactory.

Oxidizing atmospheres cause surface scaling. Furnace atmospheres should be between neutral and slightly reducing and must not fluctuate between oxidizing and reducing conditions.

Flame impingement must be avoided. For a recrystallization anneal, soaking times of 3-5 minutes per mm thickness can be used. The recommended temperatures are:

- 90-10 750-825°C
- 70-30 650-850°C.

Stress relieving is seldom used, but if required the recommended temperatures are:

- 90-10 250-500°C
- 70-30 300-400°C.

Descaling
The surface oxide films on both alloys can be very tenacious. Oxides and discolouration adjacent to welds can be removed with very fine abrasive belts or discs. If pickling is required, a hot 5-10% sulphuric acid solution containing 0.35 g/1 potassium dichromate is satisfactory. Before pickling, oxides can be broken up by a grit blast. The pickled components should be rinsed thoroughly in hot, fresh water and finally dried in hot air.

Painting
Painting copper-nickel is, strictly, unnecessary as the alloys inherently resist corrosion and biofouling. But painting is sometimes desirable, perhaps for aesthetic reasons, or to reduce the exposed metal area in a bimetallic couple and so reduce the risk of galvanic corrosion.

A thorough roughening by grit or sand blasting is crucial before paint is applied. Compared with steel, less pressure and a finer particle size should be used. Above the water line on boat hulls, epoxy followed by polyurethane coatings can be applied. Leading paint suppliers will normally prefer to recommend appropriate paint specifications based on their proprietary products for specific applications.

Welding

The appropriate welding process depends on the skills and equipment available, although a large project may justify new equipment and special training. It is highly desirable that welders are given a period of familiarization with the material and the techniques used in handling it. Insurance and inspection bodies may require qualification of both welders and welding procedures with appropriate test pieces.

The most widely available welding method is the manual metal arc (MMA or SMAW) process using flux-coated stick electrodes. This process is quite suitable for welding copper-nickel alloys and has the advantage of using relatively inexpensive equipment. The gas-shielded tungsten arc (TIG or GTAW) process can give very high quality welds even in complex joints. The gas-shielded metal arc (MIG or GMAW) process, using a continuous wire feed, is faster and can be closely controlled with modern sophisticated equipment. Relevant features of these three processes are described starting on page 10.

The general guideline for welding conditions is to avoid high levels of heat input. Manufacturers of flux-coated electrodes specify recommended current ranges. But it is not always helpful to recommend particular levels for the gas-shielded processes since welding conditions depend on the particular type of joint and sequence of runs – and for the MIG (GMAW) process, on the mode of metal transfer. Weld procedure trials are a better means of determining appropriate conditions than following data given in a table.

There is no need to pre-heat the base metal before tacking or welding unless this is necessary to ensure that the base metal is dry. To avoid microfissuring, the interpass temperature is maintained below 150°C.

Welding by TIG (GTAW) without filler metal – autogenous welding – is not recommended because of possible weld porosity from a reaction with the atmosphere. Filler metals contain additives to prevent this. Although it is possible to weld copper-nickel alloys using the oxyacetylene process, it is not a practicable or desirable process for fabrication.

Mechanical properties of welds

A 70-30 copper-nickel filler material is recommended for welding the 90-10 and 70-30 copper-nickel alloys. Because of the higher nickel content, the weld metal is stronger and more noble galvanically than the 90-10 copper-nickel base metal. When evaluating the results of test welds, a transverse bend test is not appropriate because deformation is concentrated in the relatively soft material adjacent to the weld. A longitudinal bend test should be used instead. Table 5 shows typical properties of all-weld metals.

Table 5 Typical all-weld metal mechanical properties (not to be used for design purposes)

Welding process	0.2% proof strength N/mm^2*	Tensile strength N/mm^2*	Elongation 5d%**	Hardness HV
TIG or GTAW (bare wire)	200	385	40	105
MMA or SMAW (flux coated electrode)	270	420	34	120

* 1 N/mm^2 equals 145 psi
** d is the diameter of the test piece gauge length

Welding

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TIG (GTAW) welding a 90-10 copper-nickel assembly

Preparation for welding

As with heat treatment, all traces of the elements which cause cracking (sulphur, phosphorus, lead etc.) must be removed. This includes crayons, paints, temperature indication markers, cutting fluids, oil and grease. (Fittings of other alloys, such as gunmetal – copper-tin-zinc alloy – are also a source of detrimental elements and should not be welded to copper-nickel alloys.)

The joint area should be thoroughly cleaned before welding starts. The weld preparation, and an adjacent area either side of the preparation at least 50 mm wide, must be degreased and any markings removed. Uncontaminated organic solvents should be applied with clean cloths and the area dried. The appearance of the cloths used for drying is a useful indicator of cleanliness: they should be free of any residue.

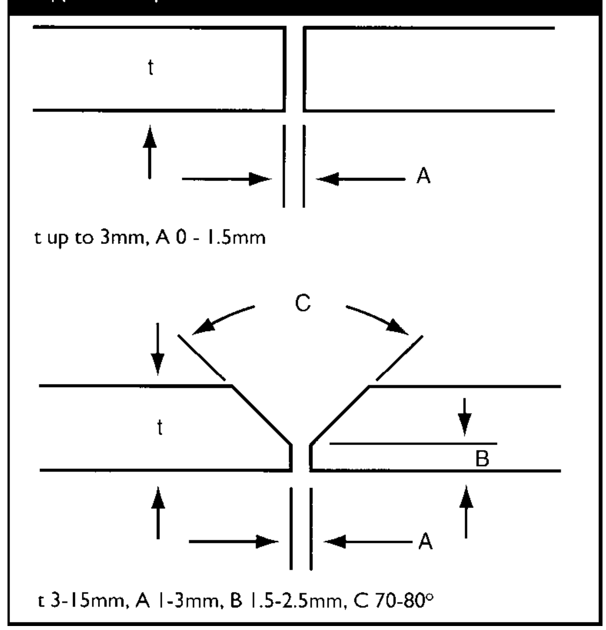
Tack welding

Because of their high coefficient of thermal expansion relative to carbon steel, copper-nickels have a greater potential for distortion when welded. Welding fixtures can help, but their use is limited to subassemblies. So tack welds should be made to maintain a uniform gap and alignment between the parts being welded. They must be positioned at about half the spacing usual for carbon steel and are preferably quite short. The TIG (GTAW) process is often used for tacking, but where it is available, MIG (GMAW) spot-welding is a convenient and well-controlled technique for the purpose. Tacks should be wire-brushed or ground to clean metal where they are to be incorporated into the joint weld metal.

Weld preparations

It is possible to weld copper-nickel up to 3mm thick with a square butt preparation. Above this thickness, a bevelled preparation must be used; the included angle of the V should be larger than for carbon steel – typically, 70° or above – because the molten weld metal is not as fluid as with carbon steels, and needs manipulation of the electrode or torch to ensure fusion with the side walls. Figure 1 shows some weld preparations.

Figure 1 Examples of weld preparations for joining copper-nickel plate



Welding

Although it is possible to weld in all customary welding positions, it is desirable to weld down-hand, which allows higher deposition rates and may demand less skill. It will normally be impracticable to turn a large structure such as a hull into the most favourable position for welding, but it is worth the effort of manipulating subassemblies for down-hand welding, rather than attempt to operate in a less favourable position.

Welding consumables

Consumables of 70-30 copper-nickel should be used to weld both alloys, although there are welding consumables of similar composition to 90-10 copper-nickel. The 70-30 consumables offer superior deposition characteristics and the corrosion resistance of 70-30 weld metal is at least comparable to each of the base metal alloys.

For welding copper-nickel to steel, nickel-copper consumables containing about 65% nickel are used as they can absorb more iron dilution from the steel than copper-nickel weld metals.
Many weld consumable manufacturers offer copper-nickel and nickel-copper electrodes and filler wires to recognized specifications – see Table 6. These contain an addition of titanium to react with atmospheric nitrogen and oxygen, which would otherwise create porosity. If weld metal porosity persists despite the use of the correct filler material, the most likely causes are inadequate shielding of the weld pool and improper weld joint cleaning. Other possible causes include an excessively long arc, moisture on the weld preparation or the flux coating being not fully dry.

Manual metal arc (MMA or SMAW)

- Flux-coated electrodes are designed to operate with direct current, electrode positive.
- No special electrode baking or drying treatment is required unless they have been exposed to the atmosphere for some time. In this case, they should be dried in an oven, e.g., 1-2 hours at 250°C.
- The electrode size should be slightly smaller than that of a carbon steel electrode under comparable conditions, taking into account the need for manipulation.

Table 6 Welding consumables – specifications

Welding process	Form	Type	AWS spec	BS2901 spec	DIN spec
MMA or SMAW	Flux coated electrode	Cu-30%NI	A5.6 ECuNi		1733: EL-CuNi30Mn
		65%Ni-Cu	A5.11 ENiCu-7		1736: EL-NiCu30Mn
TIG or GTAW MIG or GMAW	Wire in straight lengths or spools	Cu-30%Ni	A5.7 ERCuNi	Part 3 Grade C18	1733: SG-CuNi30Fe
		65%Ni-Cu	A5.14 ERNiCu-7	Part 5 Grade NA33	1736: NiCu30MnTi

AWS - American Welding Society
DIN - German Standards Institute

Welding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Manual metal arc welding of a boat hull

- Any weaving should not be more than three times the electrode diameter.
- A long arc should be avoided, since this results in weld porosity through reaction with the surrounding atmosphere.
- Start/stop positions can be unsound: reversing the electrode direction to remelt initially deposited weld metal or the crater at the end of a run can help to avoid problems.
- Slag must be removed between runs by chipping and brushing to leave a clean surface for the next run.

Gas-shielded tungsten arc (TIG or GTAW)

Unlike MMA (SMAW), separate control of heat input via the arc and filler material addition gives TIG (GTAW) a degree of flexibility which is an advantage when welding shaped joints or inserting root runs in thicker joints.

- Filler material should be incorporated and simple fusion of the base metal avoided.
- Argon and argon + 1.5% hydrogen are suitable shielding gases.
- The arc should be kept as short as possible to ensure that the shielding gas protects the weld pool adequately.
- Direct current should be used.

Gas-shielded metal arc (MIG or GMAW)

The higher capital cost of equipment and the need to buy complete spools of filler wire make MIG (GMAW) more appropriate for extensive welding operations, such as the construction of complete boat hulls. High-quality welding is made considerably easier by modern power sources and controls.

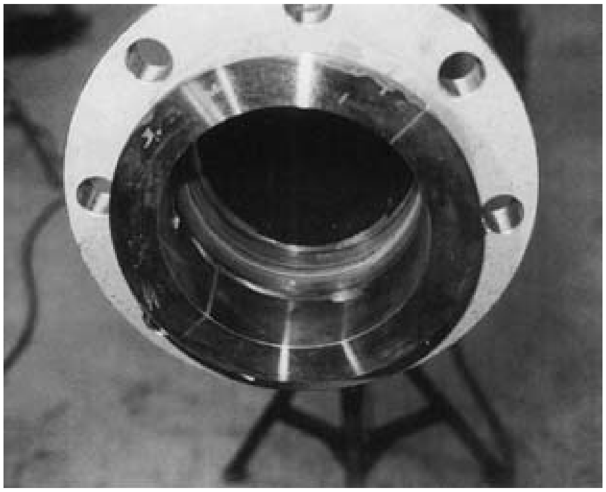
MIG (GMAW) can be operated over a range of currents to provide various transfer modes.

Dip (or short circuiting) transfer Low heat input, used for thinner sections.

Spray transfer Relatively high heat input and suitable only for thicker materials – say, above 6 mm thickness - and down-hand welding.

Pulsed-arc transfer A more advanced technique in which metal transfer is closely controlled, providing a combination of low overall heat input and adequate fusion to the base metal. It is suitable for a range of thicknesses,

Welding



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A finished weld of a flange to a pipe

although spray transfer may offer better economics for thick materials. There are substantial advantages for the operator and a greater assurance of good-quality welds than with the dip-transfer process which is prone to lack-of-fusion defects in heavier section welds. More advanced synergic welding power sources control the detachment of the droplet from the wire-effectively while reducing the number of variables to be set by the welder.

Because of the range of transfer conditions which are possible with the gas-shielded metal arc process, welding parameters can vary widely. In all cases these should be set for the equipment, and the position and thickness of the material, by careful welding procedure trials directed toward stable transfer conditions and welds of good appearance. It is not desirable simply to reproduce published welding conditions, since indicated currents not only depend on transfer mode but on the type of indicating instrument and power source in use.

- Argon or a mixture with helium is the preferred shielding gas.
- The spooled filler wire must be kept dry and not exposed to contamination.
- Attention should be paid to the effectiveness of the wire feeding system when welds have to be made some distance from the welding equipment, since filler wire is relatively soft.
- Low friction liners are essential for the feed hose.

Post-weld treatment

No heat treatment is necessary after welding. All traces of slag should be removed from joints made by the manual metal arc process and the weld area may be cleaned, for example with a rotating flap wheel or stainless steel brush, to leave a bright finish.

Inspection

Welds should be inspected visually for defects such as cracks, undercut, lack of fusion and penetration, and weld contour. Liquid dye penetrant inspection is a simple method for ensuring that there is no cracking at the surface. For critical applications, more advanced inspection techniques (e.g., radiography) are adopted, but these are not required for general fabrications.

Clad plate

Thicker plate sections – e.g., tube sheets and water boxes – can be constructed economically using steel plate which has been roll-clad with 90-10 or 70-30 copper-nickel. Plate 8 mm thick (2 mm copper-nickel, 6 mm steel) has been successfully used to build four fire boats in Italy. This type of material can have advantages, but is not so readily available as solid copper-nickel plate.

Clad plate should be handled with the care appropriate to copper-nickel alloy, not that for structural steel.

Cutting

Unlike solid copper-nickel plate, it is possible to use oxyacetylene equipment for cutting clad plate if the ratio of steel to clad thickness is 4:1 or greater (20% clad or less). The clad side of the plate is face down so that cutting starts from the steel side and the slag stream from the backing steel is a cutting agent for the cladding. This is not necessary for plasma-arc cutting, but trials may be needed to find the most suitable settings for either cutting procedure. The cut face must be ground or machined to clean metal before welding.

Welding

When designing weld procedures for respective weld metals being mixed. Otherwise, cracking is likely from the copper in carbon steel weld metal or the iron in copper-nickel weld metal. The region beside the interface between the backing material and the cladding is welded with 65% nickel-copper filler material which can cope with iron pickup from the carbon steel side. When the clad plate thickness is less than about 10 mm, 65% nickel-copper filler metal is often used for the complete weld.

When it is possible to weld from either side on plates 12 mm and thicker, the usual procedure is to weld the steel side first with a steel filler metal. The alloy side is prepared for welding by backgouging to sound metal and welded with a first pass of 65% nickel-copper alloy followed by 70-30 copper-nickel. Figure 2 shows the sequence.

When access is possible only from the steel side, the joint is prepared to give access to the copper-nickel cladding, so that it can be welded like a solid alloy. The weld joint in the steel backing is then made with the 65% nickel-copper followed by the steel filler runs.

Brazing

Copper-nickel alloys are readily brazed by all processes, although torch brazing is commonest. Since the process relies on wetting the surfaces to be joined by the brazing alloy, absolute cleanliness is essential. Fluxes alone are not capable of removing all contamination, particularly those containing lead or sulphur, and oils, paint, etc which should be removed carefully with solvents and degreasing agents. Oxides and dirt can be eliminated with emery paper or a chemical cleaning process.

If parts have been cold formed, they may contain significant internal stresses, which promote intergranular penetration by molten filler material during brazing - resulting in cracking at the joint. Removal of stresses by full annealing is not necessary; heating to 600-650°C for a few minutes is sufficient for adequate stress relief and this can be done simply with an oxyfuel torch, taking care that the part is heated uniformly.

While phosphorus-bearing brazing alloys are often recommended for joining copper alloys, they are not suitable for copper-nickels because the nickel reacts with phosphorus to form a brittle nickel phosphide phase. Silver brazing alloys (‘silver solders’) should be used. They offer a useful combination of melting range, flow characteristics and mechanical properties. They also perform well in brazed joints with copper-nickels exposed to sea water. Alloys containing cadmium are no longer recommended because of health hazards in application, but there is a range of silver-copper-zinc alloys which are suitable and safe.

For brazing pipe and fittings, preplaced brazing alloy rings are preferred over manual feeding – better control of quality and minimal use of flux (residues of which must always be removed after the joint has been made, usually by washing with hot water). The larger the pipe size, the more difficult it is to achieve uniform heating around the diameter to reach the brazing temperatures. Some organizations limit brazing to pipe diameters up to and including about 50 mm.

Furnace brazing is possible, and better where significant numbers of assemblies are to be joined.

Exothermic, endothermic or dissociated ammonia atmospheres are suitable, together with inert gas. Because of the high vapour pressure of some brazing alloy constituents, vacuum brazing is less suitable.

Tube to tubesheet fabrication

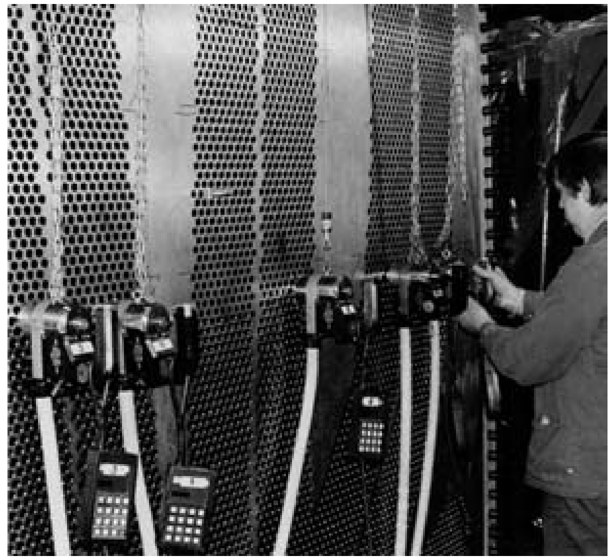
In heat exchangers and condensers, tubes are joined to tubesheets to prevent leakage between the tube side and shell side. Often the easiest and least expensive method is to expand the tube mechanically into the drilled hole in the tubesheet, usually by roller expansion. Ideally, the tubesheet should be harder and less galvanically noble than the tubes. A mechanically expanded joint may be acceptable when:

- service temperatures are under about 200°C
- tube sheets are sufficiently thick to allow rolling-in a suitable length of tube
- design pressures are relatively low
- a weld joint is not needed to support the tube bundle.

A mechanical joint is not used for severe services where a leak could present a catastrophic safety hazard.

When a tube-to-tubesheet (T/TS) weld is made in a copper-nickel construction, it is most often an automatic gas-shielded tungsten arc (TIG or GTAW) weld made either with or without filler metal. Manual welding can be used on special designs and is often the standard method for weld repairing. With manual welding, filler metal addition is recommended, particularly to avoid porosity from lack of complete gas shielding over the molten weld metal. While the TIG (GTAW) process is well adapted to make T/TS welds with thin wall tubes, other welding processes may be better suited for large-diameter and thicker wall tubes. Alternative welding processes include MMA (SMAW), MIG (GMAW) or plasma arc. Explosive welding is another joining option, although it is seldom used in copper-nickel construction.

There are many different T/TS weld joint designs used in industry and each has its particular advantages and disadvantages. Figure 3 (page 16) illustrates the common welds that can be made on the tubesheet face – flush tube, recessed tube, trepanned tube sheet, added-ring and face-side fillet weld.



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Tube to tubesheet welding of a large heat exchanger using automatic TIG (GTAW) welding heads

Selection of the particular automatic TIG (GTAW) weld joint configuration to use involves considerations as:

- joint crevice leak path size requirement
- filler metal requirements
- tubesheet heat sink
- structural flexibility
- available equipment
- tube dimensions and fillet size.

Successful T/TS welding depends critically on the accurate machining of holes, joint preparation on the tubesheet and cleaning all surfaces prior to welding. Accurately machined holes are particularly important to make sure the tungsten electrode is always positioned correctly in the weld joint.

The tubesheet should be cleaned immediately after drilling and positioned so that, during cleaning, the

Tube to tubesheet fabrication

contaminants drain from the tubesheet and do not accumulate on one surface. Compressed air should not be used to blow off the cleaning solution unless equipment is installed to remove the normal moisture and oil contamination. Dry nitrogen is often a good alternative to compressed air.

Prior to T/TS welding, it is often desirable to expand the tube into the tubesheet, for example by a 'light roll' to ensure the tube is centred in the hole for good tracking in automatic welding. A `hard roll' prior to welding increases the chance of producing a weld defect from escaping gas as the weld is being made. After welding on thicker tubesheets, the tube is often given a 'hard roll' stopping about 25mm short of the back side.

The completed T/TS weld should be inspected visually for defects. A liquid penetrant inspection is also quite standard. Other inspections might be imposed – a leak test and in some T/TS designs a radiographic inspection can be made of selected areas. Defects such as cracks or porosity should be ground out and repaired by TIG (GTAW) with filler metal.

Large heat exchanger

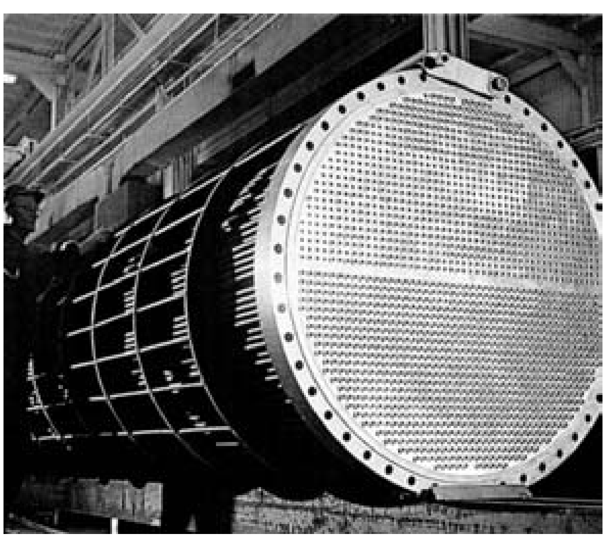
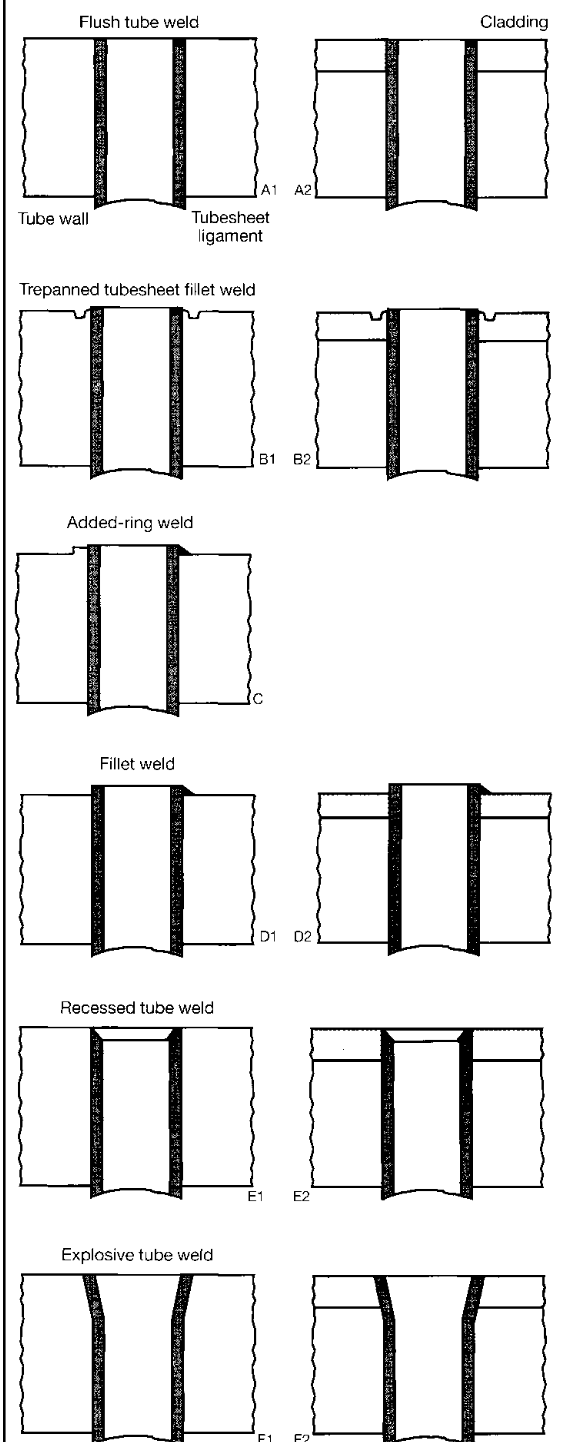


Figure 3 Typical tube weld joint preparation showing finished weld on the right side. The left-hand column is solid copper-nickel tubesheet, the right-hand column clad plate



Reynolds et al. (see Bibliography)

Boat hulls

Growth of marine organisms on the steel hulls of marine vessels has a significantly detrimental effect on their performance by increasing drag. It is customary to inhibit growth with a biocidal coating, replaced from time to time in dry dock. The obvious benefits of copper-nickel alloys in maintaining a smooth hull surface can be achieved by:

- sheathing a steel hull with copper-nickel alloy sheet
- construction of the hull from roll-bonded clad plate
- construction of the hull from solid copper-nickel alloy plate.

Techniques for sheathing a hull mainly involve dissimilar metal welds to the hull. MIG (GMAW) spot welding can be used to ensure a close fit of the sheathing to the underlying steel. This process operates automatically, so that the degree of penetration into the backing steel, and thus the iron content of the weld metal, can be controlled reproducibly. In tanker trials, sheathed panels of 90-10 copper-nickel alloy covering fully submerged, alternate wet/dry and splash zone conditions performed well over a period of two years. There was minimal corrosion and fouling and – although the surface of the exposed steel had roughened – the trial panels remained smooth.

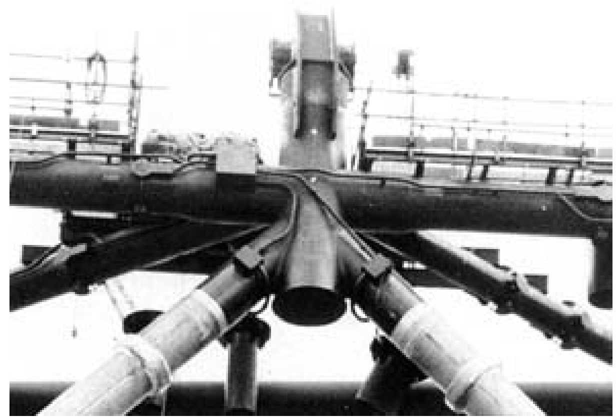
Several boats have been fabricated from roll-bonded clad plate. Four fireboats in Italy were constructed using plate of 6 mm carbon steel and 2 mm 90-10 copper-nickel alloy. When formulating a welding procedure for clad plate, the cladding and backing steel must be treated as separate components. If it is possible to weld from either side, the steel side is welded first and the assembly inverted to allow the cladding to be prepared and welded. The first run on the alloy side is of 65% Ni-Cu filler metal and the weld is completed with 70-30 copper-nickel filler metal. The sequence has to be modified when access is possible only from one side, but the transition region is always welded with nickel-copper filler metal to avoid cracking. It is possible, and may be convenient, to use the 65% NiCu filler metal throughout the joint - but there will be biofouling on the welds at the surface.

While construction from copper-nickel alloy plate is straightforward, welding to the steel framing requires dissimilar metal joints. These can be made by the techniques described, but must be protected against galvanic corrosion within the hull, usually by painting.

In 1971 Copper Mariner was the first copper-nickel hulled boat – using 6mm thick plate

Sheathing of offshore structures

The corrosion rate of steel in the splash zone varies with location and season but is generally 0.5-1.5mm/yr. This increases dramatically at the higher surface temperatures found in hot riser pipes – fluid conduits that extend from a sea floor well or pipeline to the platform structure at the sea surface. At temperatures of over 90°C, steel corrosion rates can reach 8mm/yr.



British Gas Hydrocarbon Resources Ltd

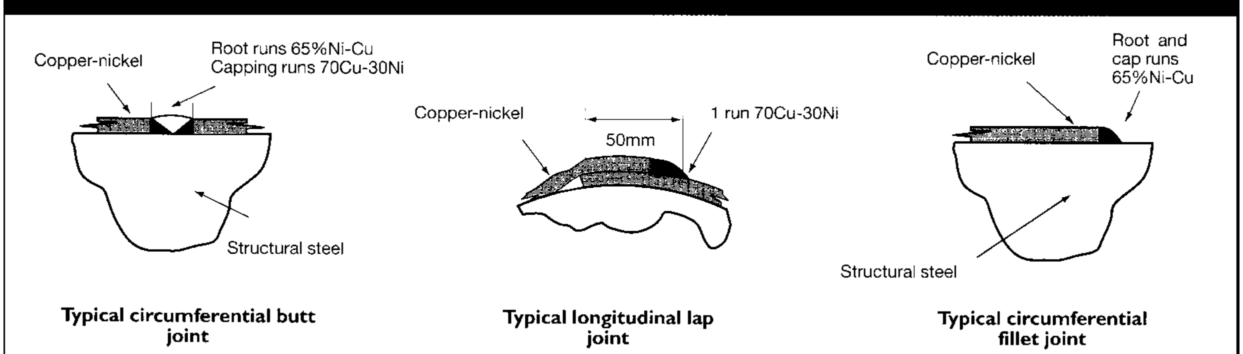
Phase I of Morecambe gas field platforms. Structural members are sheathed in the splash zone with 90-10 copper-nickel.

Splash zone sheathing is normally 3-5 mm thick. The sheathing should span at least from below mean tide level to well into the atmospheric zone. Potential galvanic corrosion on the adjacent steel is addressed by painting the top section; the bottom, submerged junction will be protected by the cathodic protection normally applied to the structure.

Attachment of the alloys has involved straps and fixings, but the normal method is welding. Both 90-10 and 70-30 alloys can be welded to steel – carefully, because of alloy mixing. The sheet is pre-formed to half cylinders and longitudinal joints are lapped so that the alloy is welded to itself. Horizontal butt welds between sections can be made directly to the steel and are often a 3-bead method such that the cap pass experiences minimum dilution from the steel. Occasionally, where the steel has a rough surface or it is not considered appropriate to weld the alloy sheathing directly to the steel riser or other structure, horizontal steel bands are initially welded to the steel and the sheathing welded to the band.

Sheathing thus involves a combination of similar and dissimilar metal welds, which are made according to the principles already discussed: nickel-copper welding consumables for part or all of joints between the copper-nickel alloy and steel to avoid the possibility of weld cracking, and 70-30 copper-nickel for the copper-nickel to copper-nickel welds. Figure 4 shows an outline of a typical cladding assembly with an indication of the types of joint involved and the weld procedure.

Figure 4 Cladding assembly in sheathing fabrication



Linings

Copper-nickel sheet can be a convenient and economic alternative to solid alloy or clad plate for lining a vessel. An early example was the construction of a water box in which the lining was fabricated as a separate component from 1.2 mm thick 90-10 copper-nickel sheet, made to fit closely into a carbon steel shell. It was then attached to the shell by a pattern of MIG (GMAW) spot welds, using an automatically timed sequence. It was necessary to ensure that the lining fit closely in the shell and was in intimate contact with it when the welds were made. Seal welds around the flanged opening completed the lining process. Automatic spot welding allowed welds to be made with a 70-30 copper-nickel alloy filler wire with reproducibly low iron dilution.

In recent years, techniques have been extensively developed for lining vessels and ducting with corrosion-resistant alloys, particularly in the power generation industry. Spot welds are usually used to minimize bulging due to the different thermal expansion of the backing material and the lining, or from the pressure variations. The lining is attached as sheets or strips by a carefully designed welding procedure. It is important that the backing material surface is thoroughly cleaned, usually by grinding and blast cleaning with abrasives to produce an uncontaminated surface. The final surface should be closely inspected and any areas of localized thinning must be repaired before lining starts.

Two welding procedures are commonly adopted for lining.

- Each sheet is fillet welded to the backing material and a third, covering bead deposited to complete the joint.
- Each strip is tack welded to the backing material, overlapping the adjacent sheet by a few centimetres. A seal weld is then made directly between the strips.

With both procedures, it is advisable to use 65% nickel-copper filler material, although 70-30 copper-nickel filler can be used for the seal weld in the second procedure.

The number and pattern of spot welds is determined by the area of sheet or strip between the welds. The reproducibility of the technique also makes it ideal for the repetitive sequence of tack welds. Fillet and seal welds are best made by the MIG (GMAW) process since it operates at relatively high speeds and can be closely controlled by modern power sources. Details and regions of complex shape may be welded by the TIG (GTAW) process: although slow, it is flexible and facilitates manipulation of the welding torch.

Throughout fabrication of a lining, care must be taken to avoid surface damage to the copper-nickel sheet; on completion, any weld spatter and discolouration must be removed. Welds should be examined visually for defects, and the absence of porosity or cracks breaking the surface of welds can be confirmed by a penetrant inspection technique.

Desalination plants

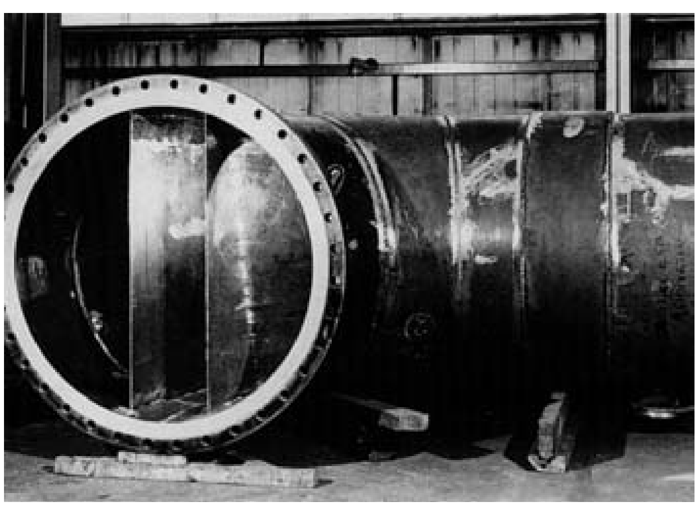
The multi-stage flash (MSF) process of desalination involves large heat exchangers producing up to 57,000 m^3 of water per day. Copper-nickel alloys are widely used to fabricate piping, waterboxes, evaporator shells, tube plates, etc. The 90-10 nickel alloy is usually used in such fabrication, although a 70-30 copper-nickel with 2% iron and 2% manganese (C71640, CW353H) is also widely used for heat exchanger tubing.

About 40 waterboxes are needed in a typical unit. The normal construction is clad plate with 2-3 mm of 90-10 copper-nickel on a mild steel plate. These have performed very reliably in many plants and are now the standard material for both raw seawater and de-aerated brine. Many hundreds are in service, with thousands of tonnes of clad plate.

Some large plants use 90-10 clad plate for the main shell. An economic choice for small standard units is solid 90-10 copper-nickel with external carbon steel reinforcements. Being able to weld the alloy directly to the steel is a key factor in this fabrication.

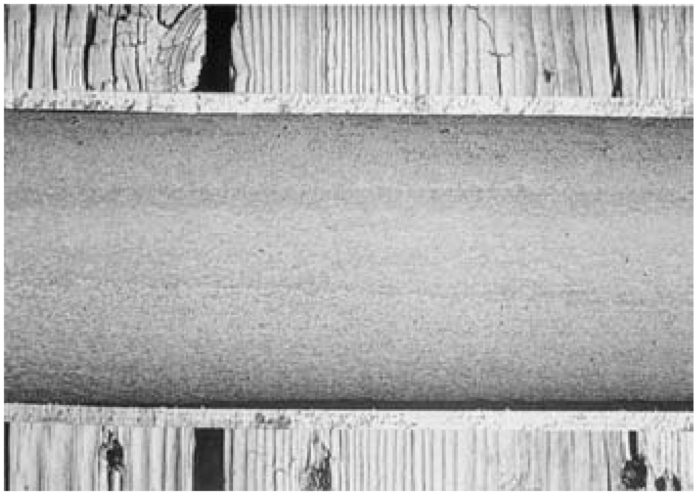
Both 90-10 and 70-30 alloys are used for tubesheets and can be welded directly to a carbon steel shell. When copper-nickel clad tubesheets are used, the cladding should be thick enough to allow for a roller expanded joint – 8-10 mm normally.

Piping of 90-10 copper-nickel is used for both natural seawater and hot de-aerated brine service. Large pipes up to 1.37 m OD are fabricated from plate; seamless pipe is used for sizes up to about 400 mm. Standard fittings such as tees, bends, reducers, saddle joints and flange connections are available for the smaller sizes. These can be welded to the pipe so that piping systems can easily be assembled. Diameters below about 50 mm OD are normally joined by brazing with silver solders.



90-10 copper-nickel brine piping for a desalination plant

Seawater corrosion resistance



Section through copper nickel tube showing protective mature surface oxide film

The resistance to seawater corrosion of copper-nickel alloys results from the formation of a thin, adherent, protective surface film which forms naturally and quickly on exposure to clean seawater. The film is complex and predominantly cuprous oxide, with the protective value enhanced by the presence of nickel and iron. The initial film forms fairly quickly over the first couple of days but takes up to three months to fully mature. This initial exposure is crucial to the long-term performance of copper-nickel.

Once a good surface film forms, the corrosion rate will continue to decrease over a period of years. For this reason, it has always been difficult to predict the life of copper-nickel alloys based on short-term exposures. Normally, corrosion rates of 0.02-0.002 mm/yr are anticipated.

Flow rates

With increasing seawater flow rate, corrosion remains low due to the resilience of the protective surface film. But when the velocity for a given geometry is such that the shear stress action of the seawater on the film is sufficient to damage it, impingement attack can result. General experience has shown that 90-10 copper-nickel can successfully be used in condensers and heat exchangers with velocities up to 2.5 m/s; the 70-30 alloy can be used up to 3 m/s. For pipeline systems, higher sea-water velocities can safely be used in larger diameter pipes as indicated by *BS MA 18 Salt Water Piping Systems in Ships* which suggested a maximum design velocity of 3.5 m/s in pipes of 100 mm and larger for 90-10 copper-nickel, and 4 m/s for the 70-30 alloy. Although these guideline values are now considered to be conservative, they work well because they take into account effects from things such as bends which cause areas of high local flow rate. Nevertheless, extreme turbulence has to be avoided – from elements like tight radius bends, partial blockages and areas downstream of partially throttled valves.

Minimum flow rates of more than 1 m/s are usually preferred to avoid sediment build-up.

The seawater velocities considered until now have been for continuous flow. Firemains are normally used for test purposes and fires, at intermittent velocities as high as 12-15 m/s. Experience has shown that these high flow rates are acceptable in such short-term operations.

Sea water corrosion resistance

The hydrodynamics of ship hulls are somewhat different to pipework systems. Experience to date has shown minimal corrosion after 14 months at 24 knots (12m/s) for the 90-10 alloy. The highest recorded velocity is 38 knots (19m/s) for a patrol boat which showed no measurable thickness loss after 200 hours at maximum operating speed. The upper service velocity for hulls is still to be established.

Sand abrasion

The effect of sand abrasion in seawater is difficult to quantify. Sand loadings of less than 200ppm rarely damage good protective films on copper-nickel alloys. Very fine sand (under 0.05mm) is tolerable up to about 1000ppm. Larger diameter sand particles tend to be increasingly abrasive to the film in the 200-1000ppm range. The 70-30 alloys have somewhat greater resistance to sand. For sand loadings of 1000ppm and for larger particles of sands in the 200-1000ppm range, a 2% manganese, 2% iron, 30% nickel, copper-nickel alloy, C71640 (CW353H), is very resistant in the waters from shallow estuaries and from intakes of desalination plants along the Arabian Gulf.

Localized corrosion

Copper-nickels have good inherent resistance to chloride pitting and crevice corrosion. Crevice corrosion is seldom found. The mechanism is a metal ion concentration cell type totally different from that of stainless steels. Any corrosion is outside the crevice and shallow.

Copper-nickels are not susceptible to chloride or sulphide stress corrosion cracking or hydrogen embrittlement and unlike brasses do not suffer cracking due to ammonia in seawater service. But ammonia can cause higher corrosion rates, although copper-nickels are more resistant than many other copper-based alloys. Copper-nickel tubing is resistant to chlorination at the dosing levels used to control biofouling. Excessive chlorination can be detrimental, as it reduces erosion-corrosion resistance.

Dealloying is not common with copper-nickel alloys. Denickelification of the 70-30 alloy has been encountered occasionally in refinery overhead condenser service, where hydrocarbon streams condense at temperatures above 150°C. This appears to be due to thermogalvanic effects resulting from local hot spots. The solution has been to remove the deposits which lead to the hot spots either by more frequent cleaning or by increasing flow rates. Ammonia in sea-water can produce a type of dealloying which looks similar to hot spot corrosion. This happens at around ambient temperature, but only under heat transfer conditions. It can be controlled by adding ferrous sulphate to the sea-water.

Galvanic behaviour

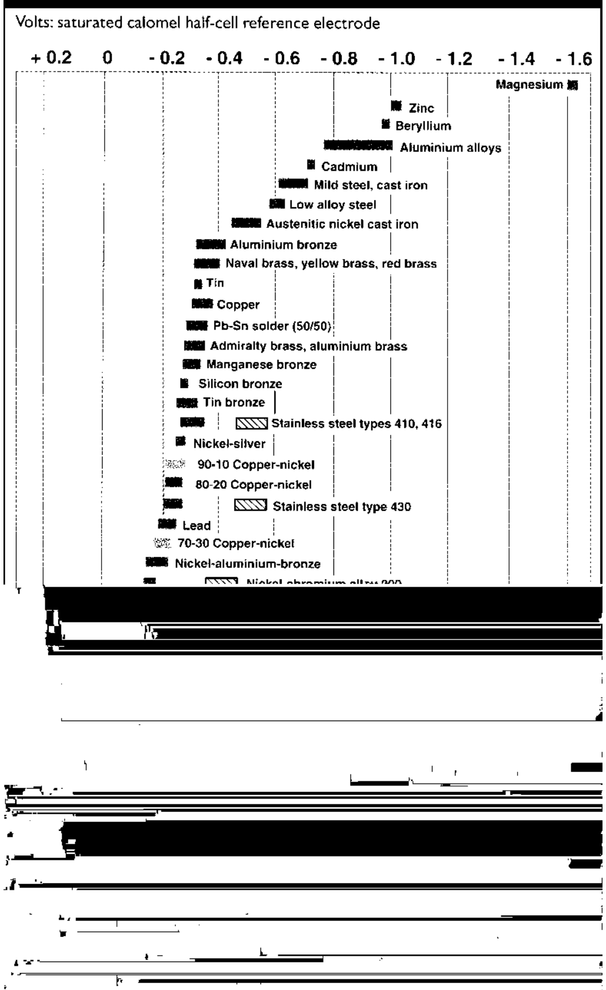
Copper-nickel alloys lie midway in the galvanic series (Figure 5): they are compatible with other copper alloys but more noble than zinc, aluminium and steel and less noble than stainless steels, nickel alloys and titanium. The 70-30 alloy is slightly more noble than the 90-10 alloy.

Handling sulphides

If exposed to polluted water, any sulphides present can interfere with surface film formation, producing a black film containing cuprous oxide and sulphide. This is not as protective as films formed in clean water and higher general corrosion rates and pitting can result. The sulphide film can be gradually replaced by an oxide film with subsequent exposure to aerated conditions, although high corrosion rates can be expected in the interim.

Seawater corrosion resistance

Figure 5 Galvanic series



However, if an established cuprous oxide film is already present, then periodic exposure to polluted water can be tolerated without damage to the film.

Sulphides are present in polluted water either as industrial effluent or when the water conditions support the growth of sulphate-reducing bacteria. They can also appear in stagnant conditions by decomposition of organic matter. Exposure to sulphides should be restricted wherever possible and particularly during the first few months of contact with seawater while the oxide film is maturing.

For condensers and piping systems, fitting out and commissioning are the likeliest stages for sulphide problems. Whether in a ship, platform topside or power plant, aerated, clean seawater should ideally be circulated at start-up for long enough to form a good protective film. This film provides a high degree of corrosion protection against subsequent sulphides.

Where it is not possible to use clean seawater, circulating the system initially with fresh water containing ferrous sulphate additive will encourage effective film formation.

After brief exposure to sulphides during normal operation, clean water should be restored as soon as possible. Normal harbour turnaround times – which often involve exposure to polluted water – have rarely led to significant problems.

Metal surfaces can be exposed to sulphides under deposits or sediment caused by sulphate-reducing bacteria, for example where deposits are not removed from tubing. The remedy is proper scheduled cleaning – often water flushing or cleaning with non-metallic brushes at 2-6 month intervals. Sponge ball cleaning is an alternative. Such procedures are also necessary to restore optimum heat transfer.

Where there is long-term exposure to de-aerated, sulphide-containing seawater, or regular alternating exposure to sulphide pollution and aeration, copper-nickel is generally not recommended.

Ferrous sulphate dosing treatment
Ferrous sulphate dosing is not essential to the successful performance of copper-nickel but can be a remedy, or a precaution if trouble is likely. Most ships in service have operated successfully without any ferrous sulphate dosing.

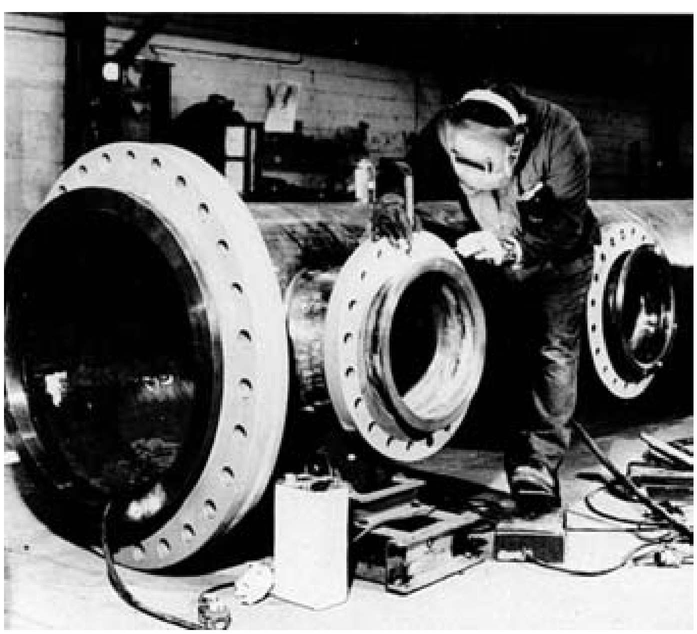
Seawater corrosion resistance

Ferrous sulphate treatment has been found to suppress corrosion rates of copper-nickel in both polluted and unpolluted conditions. For commissioning, which can last from a few weeks to 3 months, the ferrous sulphate content of the cooling water can be set up to about 2-3ppm, following practical experience. An alternative is to encourage good initial film formation during fitting-out, then leave fresh water containing 5ppm ferrous sulphate in the system for a day. After this, the system can be used for normal fitting-out purposes, but 5ppm ferrous sulphate should be added to the system and circulated for an hour a day throughout the fitting-out period. This is also useful when systems are retubed or renewed.

During normal service on ships, additional ferrous sulphate dosing is seldom required. If, however, exposure to known polluted water is anticipated (e.g., when entering port), a reasonable additional precaution would be to add 5ppm ferrous sulphate for one hour per day from three days before entering until leaving. One treatment a week can be applied throughout prolonged voyages. Chlorination treatment and ferrous sulphate treatment should not be done simultaneously.

An alternative method of adding iron is to use a driven iron anode. This is more to maintain a protective layer than to form one, and reduces biofouling resistance.

Other pretreatment compounds have been used with variable success. Sodium dimethyldithiocarbamate has been used by the British and German navies.



Copper Development Association

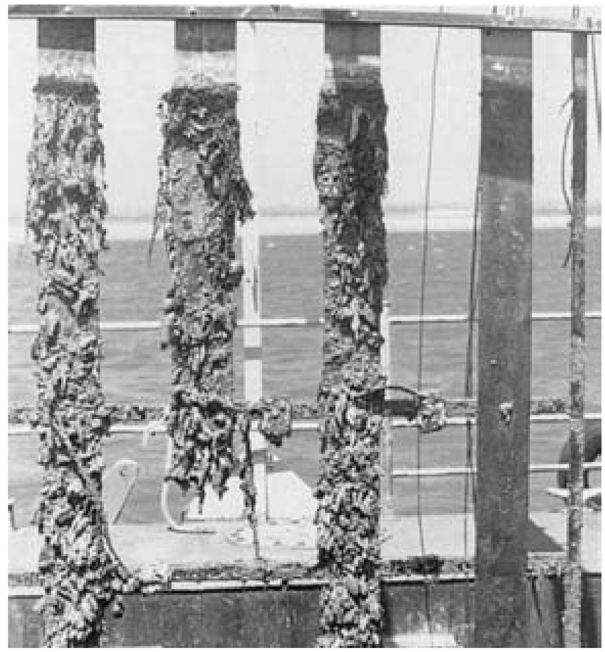
Inlet/outlet manifolds for seawater course filtration unit in 90-10 copper-nickel

Biofouling resistance

Copper-nickel alloys have a high inherent resistance to macrofouling. This quality can be exploited to reduce cleaning of pipework or condensers, decrease wave drag and reduce fouling removal costs of platform structures. Optimum biofouling resistance requires the alloy to be freely exposed or electrically insulated from less noble alloys.

In offshore sheathing, neoprene or concrete have been used to insulate the sheathing from the cathodically protected (CP) structures. However, it is now known that some fouling reduction is obtained even when CP is applied. Table 7 shows the results of 10-year studies at LaQue Corrosion Services in North Carolina. The isolated pilings show negligible build-up. When directly connected to the steel, with or without cathodic protection, the fouling rate was only 44% of that on the plain steel piling. Similar results have been found in service. A light scraping action can readily remove any biofouling attachment which does form.

Long-term exposure of copper-nickel to quiet or stagnant seawater can lead to a thickening of microfouling (slimes) sufficient to allow some colonization of macrofoulants. As these will not be as rigorously attached as on many other substrates, experience has shown that they will periodically slough away or can be again removed by a light scraping.



IMI Yorkshire Alloys Ltd

Exposure panels (left to right): steel, 90-10 copper-nickel sheathed steel, copper-nickel – all three protected with aluminium anodes – and freely exposed copper-nickel. After 12 months' exposure at Langstone Harbour, UK, there was no fouling on the freely exposed panel.

Table 7 Biofouling mass on copper-nickel sheathed test pilings after 5 and 10 years' exposure

Piling	Biofouling mass kg/m^2	Percentage of area covered
Bare steel control (not sheathed)		
5-year removal	18	100
10-year removal	12	100
Concrete insulated		
5-year removal	0.36	1.9
10-year removal	0.14	1.2
Directly welded		
5-year removal	7.95	44.3
10-year removal	4.43	36.8
Rubber insulated		
5-year removal	0.26	1.4
10-year removal	0.62	5.3

Checklist

FOR THE BEST RESISTANCE TO CORROSION AND BIOFOULING

- Copper-nickel from a reputable supplier and to international standards
- Cleanliness is the watchword for fabrication of copper-nickels
- 70-30 copper-nickel consumables used for similar welds in 90-10 and 70-30 copper-nickel
- 65% nickel-copper consumables used for copper-nickel-steel dissimilar welds
- Maximum velocity limits for the alloys not exceeded
- Velocity raisers – e.g., sharp angled bends in pipe systems – avoided
- No polluted water used during commissioning
- Ferrous sulphate added to enhance the protective film formation if extra safeguard required
- For best biofouling resistance, copper-nickels insulated electrically from less noble alloys

The 70-30 copper-nickel hull of the *Asperida* after 12 years in service

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