



Copper Development
Association

Copper Alliance



Copper-nickel Welding and Fabrication

Handling | Welding | Properties
Resistance to Corrosion and Biofouling | Important Applications

PERFORMANCE MATTERS

Copper-nickel Welding and Fabrication

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**Copper Development
Association**

Copper Alliance

Copper Development Association is a non-trading organisation that promotes and supports the use of copper based on its superior technical performance and its contribution to a higher quality of life. Its services, which include the provision of technical advice and information, are available to those interested in the utilisation of copper and copper alloys in all their aspects. The Association also provides a link between research and the user industries and is part of an international network of trade associations, the Copper Alliance™.



**Copper Development
Association Inc.**

Copper Alliance

Copper Development Association Inc is a U.S.-based, not-for-profit association of the global copper industry, influencing the use of copper and copper alloys through research, development and education, as well as technical and end-user support. CDA is committed to promoting the proper use of copper materials in sustainable, efficient applications for business, industry and the home.



The Nickel Institute is an international, non-profit organisation which promotes the production, use and re-use (through recycling) of nickel in a socially and environmentally responsible manner. They offer free technical knowledge about nickel, its properties and uses to ensure optimum performance, safe handling and use. They are supported by most of the world's producers of nickel and have offices in Belgium, Canada, China, Japan and U.S.A.

Cover page picture acknowledgement:

TIG welding 90-10 copper-nickel straight pipe to a bend
(Courtesy Eucaro Buntmetall GmbH)



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Finished weld showing root penetration on pipe bore
(Courtesy Eucaro Buntmetall GmbH)

1.0 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 and 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/heat exchanger service for many of the world's navies, floating production storage and offloading vessels and merchant ships. They are used in desalination, power plants and offshore fire water systems, and for the sheathed splash zone protection of oil and gas platform legs. 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.



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

2.0 The Alloys

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 seawater and to overall corrosion.

2.1 Standards

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

2.2 Composition

The chemical composition ranges for the two alloys vary between the different standards. When materials are intended for welding applications, the maximum limits for some specific impurities need to be restricted because of their effects on hot ductility, and thus on weldability. Examples of preferred limits for Zn, C, Pb, S and P are shown in Table 2.

2.3 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 and retain their mechanical strength and ductility down to cryogenic temperatures.

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



90-10 copper-nickel pipe fabrication for ship seawater system

Table 1 – Designations in Standards for 90-10 and 70-30 Copper-nickel Alloys

Alloy	ASTM/UNS	ISO	CEN
90-10	C70600 C70620*	CuNi10Fe1Mn	CW352H
70-30	C71500 C71520*	CuNi30Fe1Mn	CW354H

*C70620 and C71520 are intended for products that will be subsequently welded

Table 2 – UNS Chemical Composition (%) of 90-10 and 70-30 Alloys for Welding Applications

Alloy	UNS No	Cu Min.	Ni	Fe	Mn Max.	Zn Max.	C Max.	Pb Max.	S Max.	P Max.	Other Max.
90-10	C70620	>86.5	9-11	1-1.8	1.0	0.5	0.05	0.02	0.02	0.02	0.5
70-30	C71520	>65.0	29-33	0.4-1	1.0	0.5	0.05	0.02	0.02	0.02	0.5

Table 3 – Typical Mechanical Properties of Annealed Copper-nickel Sheet and Plate (taken from EN1652:1997)

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

* 1N/mm² is equivalent to 145 psi

Table 4 – Typical Physical Properties of Copper-nickels and Steel

	Units	90-10	70-30	Plain Carbon Steel
Density	kg/dm ³	8.90	8.95	7.85
Melting range	°C	1100-1145	1170-1240	1460-1490
Specific heat	J/kgK	377	377	485
Thermal conductivity	W/mK	40	29	50
Coefficient of linear expansion 10-300°C	10 ⁻⁶ /K	17	16	12
Electrical resistivity at 20°C	microhm/cm	19	34	30
Modulus of elasticity	GPa	135	152	210
Modulus of rigidity	GPa	50	56	81

Table 4 compares various physical properties with those of steel. Additionally, 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 of 750°C is normally required to achieve a low permeability.

An example of a copper-nickel application designed to benefit from its fabricability and corrosion properties is shown here. It is a flanged strainer to be used as part of the seawater system for a 110m yacht. It is made from 90-10 copper-nickel and separates larger debris and hard fouling such as mussels, barnacles, stones and weeds which would otherwise enter, block and cause obstructions in the system. The strainer has good resistance to the seawater with an added benefit of deterring biofouling growth on its interior.



(Courtesy Eucaro Buntmetall GmbH)

3.0 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 trace 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.
- Openings of pipes and fittings must be protected on completion of fabrication to prevent ingress of dirt etc. before installation.

3.1 Cutting and Machining

Copper-nickels can be cut using most conventional cutting processes, with the exception of oxy-fuel cutting. High-speed abrasive wheels work well for bevelling edges and trimming material. Band saws or shears may be used for cutting, but allowance made for the alloys' relative softness and ductility. Plasma-arc cutting is fast, accurate and economical. Laser and abrasive water jet cutting are also possible.

Although copper-nickels are not as readily machined as free-cutting brass, they are much easier to machine than materials, such as stainless steels, which work harden rapidly: they can be ranked with aluminium bronze and phosphor bronze alloys. More details and recommendations are given in '*Recommended Machining Parameters for Copper and Copper Alloys*', *DKI Monograph i.18*.



Plasma cutting copper-nickel plate
(Courtesy Eucaro Buntmetall GmbH)

3.2 Forming

Copper-nickels can be hot or cold formed, although cold working is preferred; a maximum of 50% reduction is achievable before a full inter-stage anneal becomes necessary. A 20% cold reduction approximately halves the as-annealed elongation and doubles the proof strength. Hot working is carried out at 850-950°C (90-10) or 925-1025°C (70-30) but can lead to hot cracking in inexperienced hands.

Tubes can be bent by a range of methods, including rotary draw bending, 3-roll bending, compression bending and ram bending (press bending). When bending copper-nickel, a mandrel and wiper die are also applied for support (mandrel bending). Care must be taken to get smooth bends and avoid wrinkling, because liquid turbulence in service can lead to impingement attack. Bends with a tube bend radius of twice the tube diameter can be produced. Smaller radii require prefabricated bends.

3.3 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 such as sulphur, phosphorus, lead and other low melting point metals, sources of which include paints, marking crayons, lubricating grease and fluids. Fuels used must be low in sulphur; normally, fuel oils containing less than 0.5% by weight of sulphur are satisfactory.

Oxidising atmospheres cause surface scaling and therefore furnace atmospheres should be between neutral and slightly reducing and must not fluctuate between oxidising and reducing conditions. Flame impingement must be avoided.

For a full anneal, soaking times of 3-5 minutes per mm thickness are appropriate.



Rotary draw bending copper-nickel pipe using a mandrel (Courtesy Eucaro Buntmetall GmbH)

The recommended temperatures are:

- 90-10 750-825°C
- 70-30 650-850°C.

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

- 90-10 250-500°C
- 70-30 300-400°C.

3.4 Descaling

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 0.35g/l 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.

3.5 Painting

Painting copper-nickel is strictly unnecessary as the alloys inherently resist corrosion and biofouling. However, it 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 treating steel, a finer particle size and less pressure 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.

4.0 Welding



TIG welding 3rd weld run in joint with pulled T piece
(Courtesy Eucaro Buntmetall GmbH)

Copper-nickels can be readily welded by all conventional processes and, since they have a simple metallurgical structure, do not require preheat or post-weld heat treatment. However, it is essential that requirements for preparation, particularly cleanliness, are carefully followed and that welders undergo a period of familiarisation with the particular characteristics of these alloys if they are not to encounter problems. Automatic welding, including orbital welding of pipe, may also be appropriate.

In some applications, insurance and inspection bodies may require qualification of both welders and welding procedures to appropriate standards. A welding procedure specification (WPS) should be prepared in all cases.

Since the predominant application of copper-nickels is in the form of relatively thin-walled pipe, the tungsten inert gas (TIG), otherwise known as the gas-shielded tungsten-arc (GTAW), welding process is frequently used, both for joining pipe sections and for attaching fittings and flanges. The most widely available welding process is the manual metal arc (MMA), otherwise known as shielded metal arc (SMAW), using flux-coated stick electrodes; this process is quite suitable for welding copper-nickel alloys and has the advantage of using relatively inexpensive equipment. For thicker materials, above 6mm, the TIG (GTAW) process can be used for the root run before completion of the weld by the MMA (SMAW) process. The gas-shielded metal arc (MIG), otherwise known as gas-shielded metal arc (GMAW) process, using a continuous wire feed, is faster and

can be closely controlled with modern sophisticated equipment. Relevant features of these three processes follow.

4.1 Preparation for Welding

If stored correctly, material to be welded should be in a generally clean condition. Dirt of any kind must be removed along with residual oil and grease. Particular attention should be given to sources of the elements that can cause cracking or micro-fissuring in the weld, which can originate from crayon or paint identification markings, temperature indication markers, and other contaminants. (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. Particular attention should be paid to the weld preparation and an adjacent area at least 10mm wide, preferably wider, either side of the preparation, which can be degreased with an uncontaminated organic solvent applied with a fine abrasive pad or a clean cloth. The area should be dried with clean cloths. Their appearance after use is an indicator of cleanliness: they should be free from any residue.

4.2 Tack Welding

Because of their high coefficient of thermal expansion relative to carbon steel, copper-nickels have a greater potential for distortion when welded. Weld fixtures can help, but their use is limited to sub-assemblies. Therefore 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.

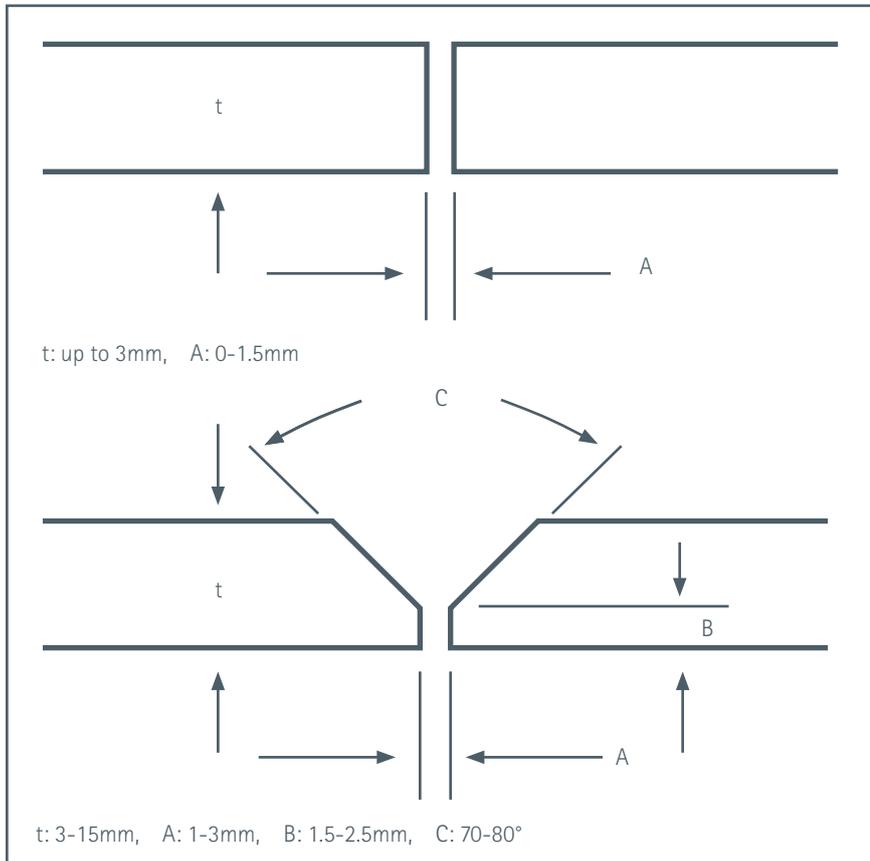


Figure 1 – Examples of weld preparations for joining copper-nickel plate

4.3 Weld Preparations

It is possible to weld copper-nickel up to 3mm thick with a square butt preparation. However, autogenous welding should not be attempted, since this will result in porous welds due to the absence of effective deoxidisers in the alloys. 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 more - because the molten weld metal is not as fluid as with carbon steels, and manipulation of the electrode or torch is necessary to ensure fusion with the side walls. Figure 1 shows some weld preparations.

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 often be impracticable to turn large or complex structures into this most favourable position for welding, but it is worth the effort of manipulating sub-assemblies for down-hand welding, where possible.

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.

4.4 Welding Consumables

While consumables are available that deposit weld metal similar in composition to the 90-10 copper-nickel alloy, welds made with them may not have adequate corrosion resistance for all applications. Consumables for the 70-30 alloy, on the other hand, offer superior deposition characteristics and the corrosion resistance of 70-30 weld metal is at least comparable to each of the base metal alloys. These consumables are therefore recommended for both types of alloy.

For welding copper-nickel to steel, nickel-copper consumables containing about 65% Ni are used as the weld metal can absorb more iron dilution from the steel without cracking than copper-nickel weld metals.

These consumables are available as flux-coated electrodes and bare wires to recognised specifications from most of the major suppliers - see Table 5. 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 use of coated electrodes which are not fully dry.

4.5 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, eg 1-2 hours at 250°C.
- The electrode size should be slightly smaller than that selected for a carbon steel electrode under comparable conditions, taking into account the need for manipulation.
- 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.

Table 5 – Welding Consumables – Specifications

Welding Process	Form	Type	AWS Spec	BS Spec
MMA (SMAW)	Flux-coated electrode	Cu-30% Ni	A5.6 ECuNi	In draft
		65% Ni-Cu	A5.11 ENiCu-7	BS EN ISO 14172 E Ni 4060
TIG (GTAW) MIG (GMAW)	Wire in straight lengths or spools	Cu-30% Ni	A5.7 ERCuNi	BS EN ISO 24373 S Cu 7158
		65% Ni-Cu	A5.14 ERNiCu-7	BS EN ISO 18274 S Ni 4060

AWS - American Welding Society
BS - British Standards Institution

4.6 Gas-shielded Tungsten Arc (TIG or GTAW)

Unlike the MMA (SMAW) process, 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. It is the process of choice for welding thin-walled pipe in the workshop or under conditions where a stable gas shield can be assured.

- Filler material should be incorporated and simple fusion of the base metal avoided.
- A backing gas, normally argon, must be used when making a root run in a pipe weld.
- Argon is a suitable shielding gas.
- 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.



Manual metal arc welding of a boat hull



TIG (GTAW) weld process
(Courtesy Eucaro Buntmetall GmbH)



TIG (GTAW) welding 90-10 copper-nickel assembly. Note baffle for backing gas supply at root run stage (Courtesy Eucaro Buntmetall GmbH)

4.7 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. The process is less used for copper-nickels than those discussed earlier.

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. Modern power sources and electronic systems permit close control of metal transfer.

Pulsed-arc transfer - A technique which provides a combination of low overall heat input and adequate fusion to the base metal. It is suitable for a range of material thicknesses.

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

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 towards stable transfer conditions and welds of good appearance.

- 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.

4.8 Post-weld Treatment

No heat treatment is necessary after welding. All traces of spatter should be removed from joints, including slag from 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.

4.9 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 detecting surface defects. For critical applications, more advanced inspection techniques (e.g. radiography) may be specified, but these are not usually required for general fabrications.

4.10 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 6 shows typical properties of 70-30 all-weld-metals determined from test pieces oriented parallel to the weld axis.

Table 6 – Typical All-weld Metal Mechanical Properties Based on 70-30 Consumables (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 (GTAW)	200	385	40	105
MMA (SMAW)	270	420	34	120

* d is the diameter of the test piece gauge length



Butt weld showing area which had been cleaned after welding (Courtesy Eucaro Buntmetall GmbH)



Pipe assembly showing both cold pulled T pieces and welded saddle connections (Courtesy Eucaro Buntmetall GmbH)

5.0 Clad Plate

Thicker plate sections - eg tubesheets and water boxes - can be constructed economically using steel plate which has been roll-clad with 90-10 or 70-30 copper-nickel. 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.

5.1 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 placed 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.

5.2 Welding

When designing weld procedures for clad plate, it is necessary to treat the cladding and backing material as separate components and to avoid the 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 pick-up from the carbon steel side. When the clad plate thickness is less than about 10mm, 65% nickel-copper filler metal is often used for the complete weld.

When it is possible to weld from either side on plates 12mm 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 back-gouging 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.

With a preparation from the cladding side, the joint is partially filled with steel weld metal and completed with a combination of 65% nickel-copper filler and 70-30 copper-nickel filler.

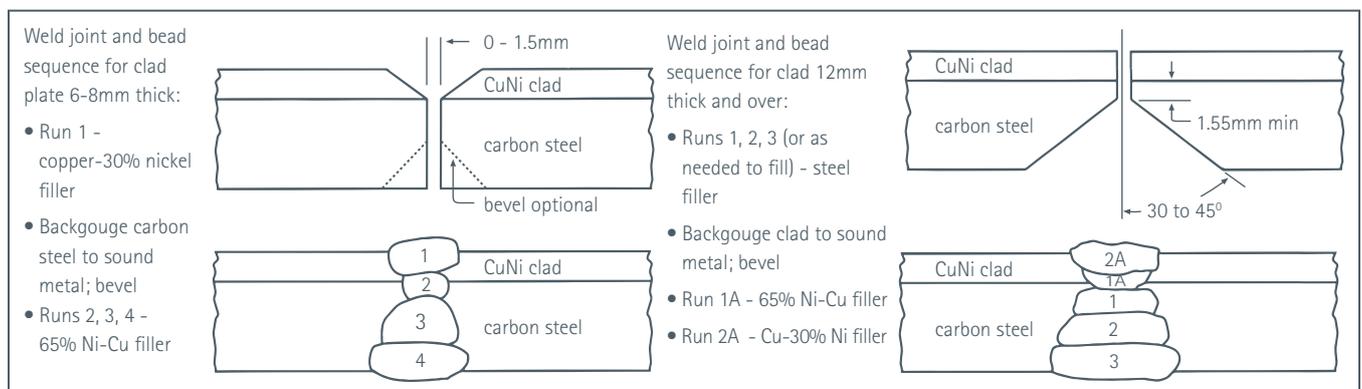


Figure 2 – Examples of run sequence for welding copper-nickel clad plate

6.0 Brazing

Copper-nickel alloys are readily brazed by all processes, although torch brazing is the most common. 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 oxy-fuel 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-based 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 where copper-nickels are exposed to seawater. 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, pre-placed brazing alloy rings are preferred over manual feeding, giving 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 organisations limit brazing to pipe diameters up to and including about 50mm.

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.



Capillary brazing of a sleeve to a pipe using a silver solder
(Courtesy Eucaro Buntmetall GmbH)

7.0 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
- tubesheets 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 made by an automatic gas-shielded tungsten arc (TIG or GTAW)

process, either with or without filler metal. Manual welding can be used on special designs and is often the standard method for weld repairing; filler metal addition is essential here, to avoid weld porosity. 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 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.

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

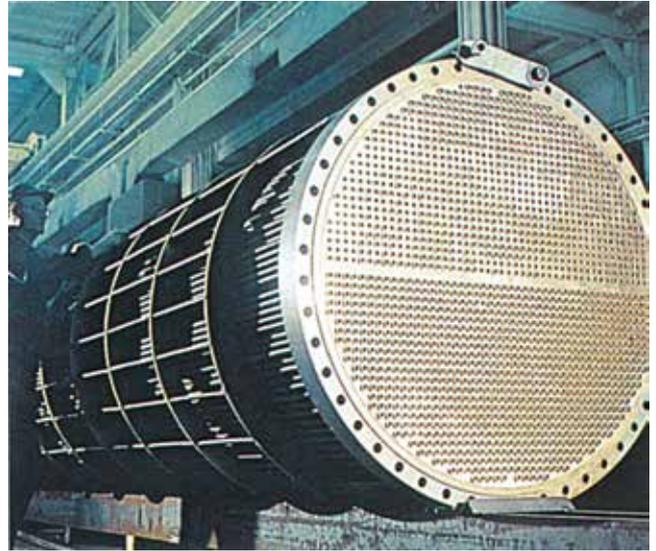
The tubesheet should be cleaned immediately after drilling and positioned so that, during cleaning, the contaminants drain from the tubesheet and do not accumulate on one surface. Compressed air should not be used to blow off the cleaning solution unless equipment is installed to remove moisture and oil contamination from the air. Dry nitrogen is often a good alternative to compressed air.



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

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

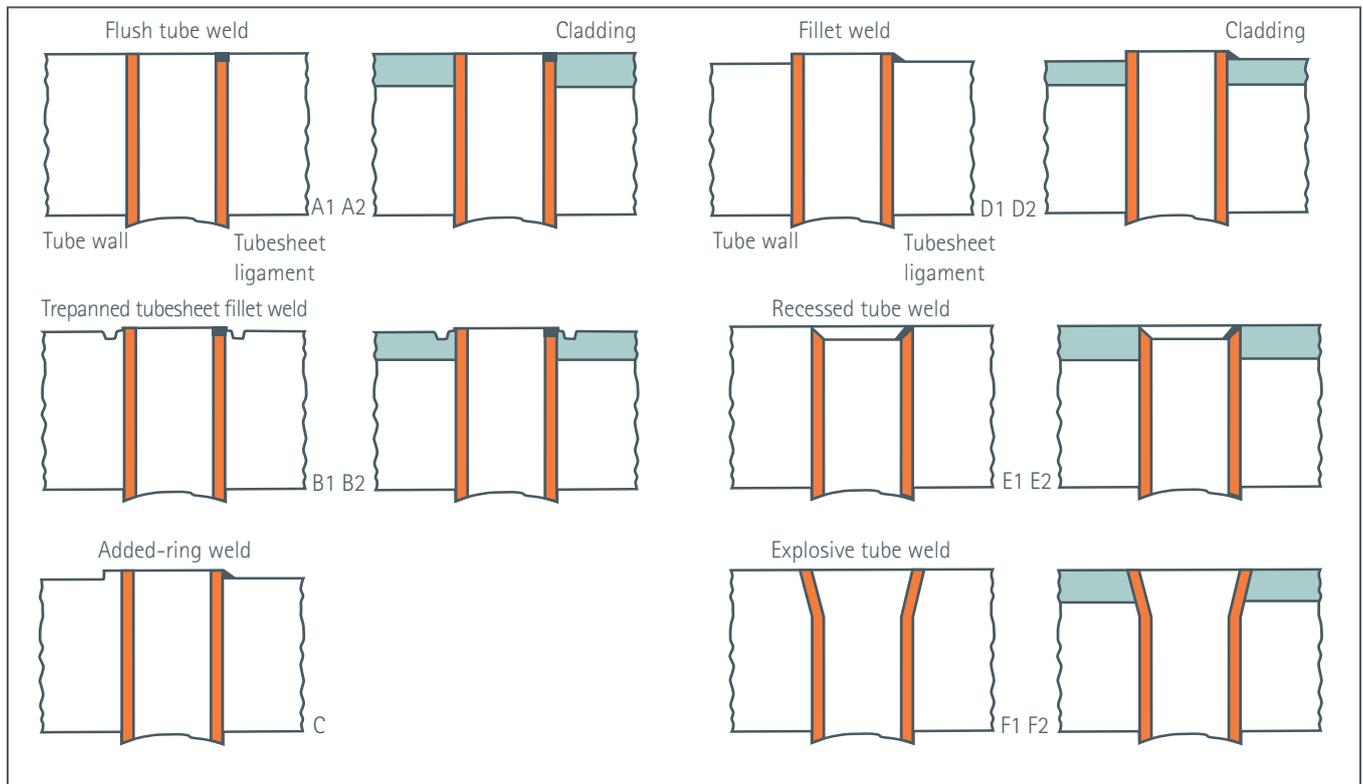
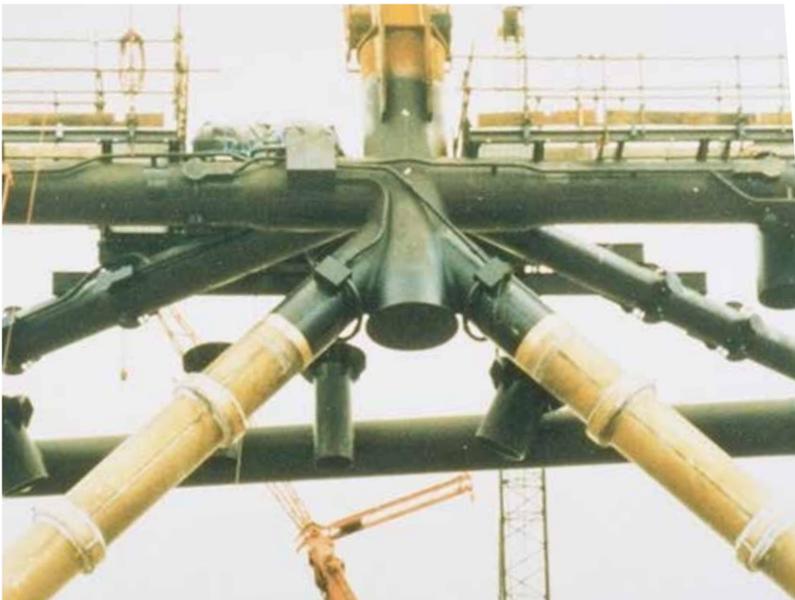


Figure 3 – Typical tube weld joint preparations showing finished weld on the right side. 1st and 3rd columns are solid copper-nickel tubesheet; the 2nd and 4th columns are clad plate (ex Reynolds et al - see Bibliography)

8.0 Sheathing and Cladding of Offshore Structures



90-10 copper-nickel splash zone protection on a platform in the Morecambe Field, UK. The sheathing has been in service over 25 years
(Courtesy Centrica Energy Upstream, East Irish Sea)



Structural members sheathed in 90-10 copper-nickel during construction of the Phase 1 Morecambe gas field platforms
(Courtesy Centrica Energy Upstream, East Irish Sea)

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.

Splash zone sheathing is normally 3-5mm 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 direct 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 direct to the steel riser or other structure, horizontal steel bands are initially welded to the steel and the sheathing welded to the band.

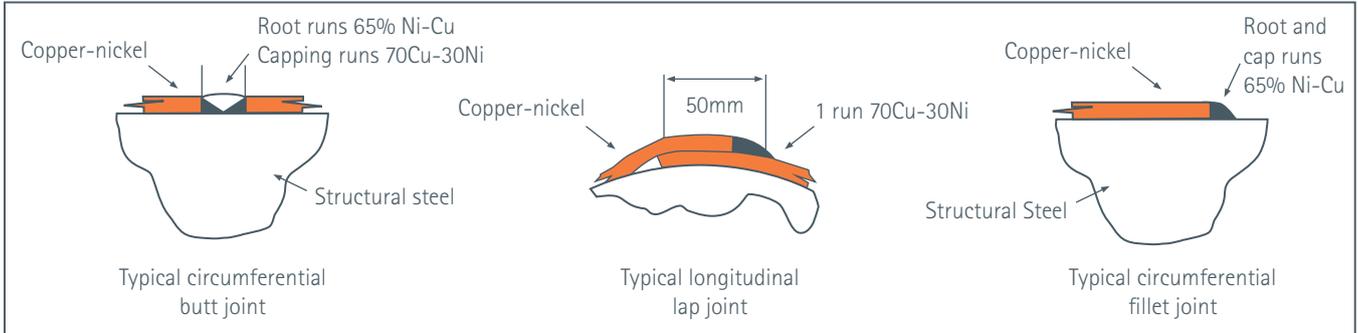


Figure 4 – Typical attachments for platform sheathing

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 sheathing assembly used on offshore platform legs with an indication of the types of joint involved and the weld procedure.

For offshore renewable power, the combination of high corrosion resistance and a natural low adherence by biofouling can also be used where personnel transfer from the boats to the structures. Figure 5 shows a prototype landing stage (patent pending) designed for access to offshore wind turbine towers. Larger diameter pipe sections are made from steel with a complete outer cladding of around 5mm thick 90-10 copper-nickel, whereas the ladder rungs are straight copper-nickel section. Welding of the clad pipes involves procedures similar to those of clad plate described in Section 5.0.



Figure 5 - Copper-nickel boat landing stage (Courtesy of KME Germany GmbH & Co. KG)

9.0 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 1.2mm 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 fitted 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 minimise 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 localised 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. 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.

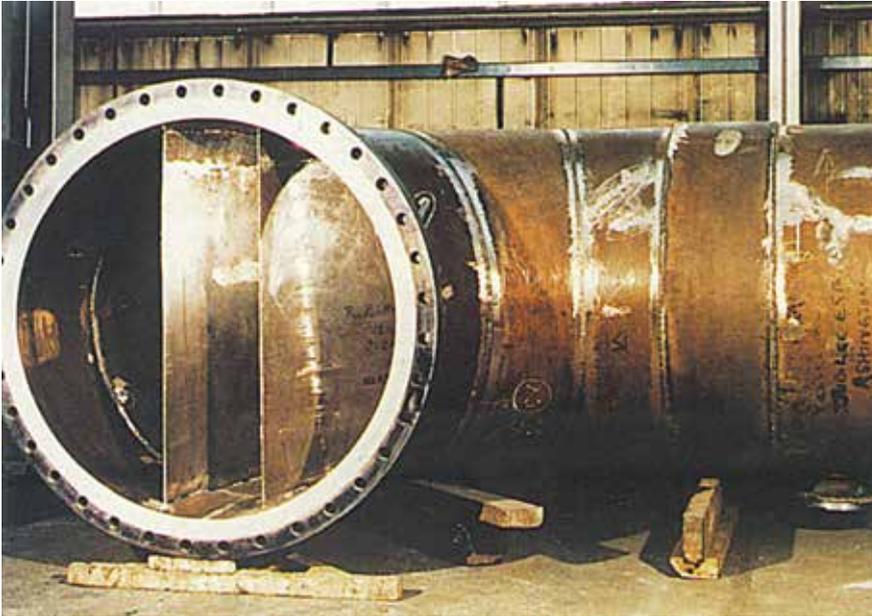
Throughout fabrication of a lining, care must be taken to avoid surface damage to the copper-nickel sheet; on completion, any weld spatter and discoloration must be removed. Welds should be examined visually for defects and the absence of porosity or cracks breaking the surface of welds can be confirmed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

Proprietary processes are also available; an example is the lining of steel pipe with 90-10 copper-nickel as shown below. In this instance, diameters up to 2.5m can be produced with the pipe manufactured from carbon steel plate and a 90-10 copper-nickel liner sheet. There is no necessity for a metallurgical bonding between the two layers as the pipe forming process creates a tight mechanical fit and the weld design provides a full seal.



Large diameter steel pipe manufactured with 90-10 copper-nickel inner liner (Courtesy of KME Germany GmbH & Co. KG/Bergrohr GmbH)

10.0 Desalination Plants



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

The multi-stage flash (MSF) process of desalination involves large heat exchangers producing up to 57,000m³ 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.

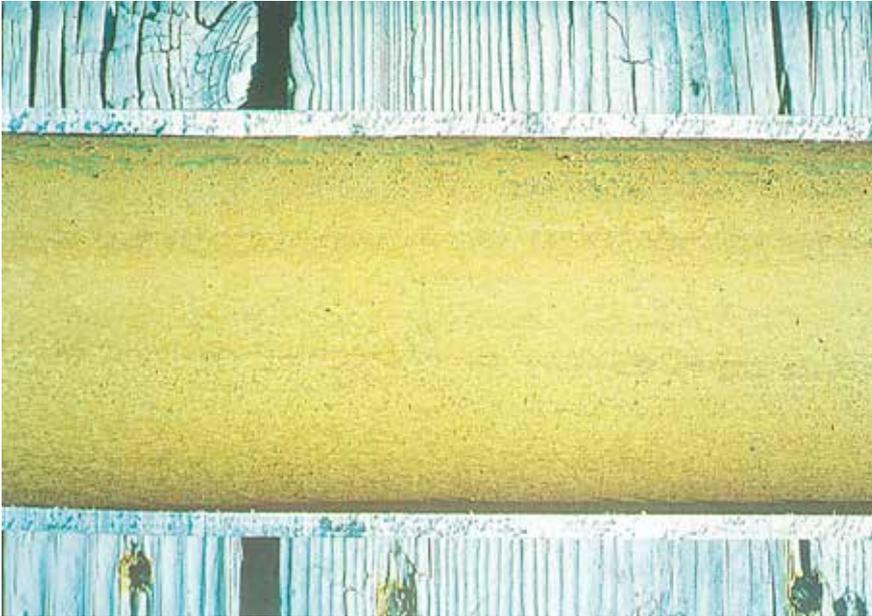
About 40 waterboxes are needed in a typical unit. The normal construction is clad plate with 2-3mm of 90-10 copper-nickel on a mild steel plate. These have performed very reliably in many plants for both raw seawater and de-aerated brine. Many hundreds are in service, with thousands of tonnes of clad 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 direct 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 - 8-10mm normally.

Piping of 90-10 copper-nickel is used for both natural seawater and hot de-aerated brine service. Large pipes up to 1.37m OD are fabricated from plate; seamless pipe is used for sizes up to about 400mm. Standard fittings like 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 50mm OD are normally joined by brazing with silver solders.

11.0 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 0.02–0.002mm/year are anticipated.

11.1 Flow Rates

With increasing seawater flow rate, corrosion remains low due to the resilience of the protective surface film. However, 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 2.5m/s; the 70-30 alloy can be used up to 3m/s. For pipeline systems, higher seawater velocities can safely be used in larger diameter pipes as indicated by BS MA18 Salt Water Piping Systems in Ships, which suggested a maximum design velocity of 3.5m/s in pipes of 100mm and larger for 90-10 copper-nickel, and 4m/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 like 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 1m/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 12-15m/s. Experience has shown that these high flow rates are acceptable in such short-term operations.

The hydrodynamics around offshore structures are somewhat different to pipework systems. Experience to date for ship hulls 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.

11.2 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), has better resistance in the waters from shallow estuaries and from intakes of desalination plants along the Arabian Gulf.

11.3 Localised 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 to 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 seawater 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 seawater.

11.4 Galvanic Behaviour

Copper-nickel alloys lie mid-way in the galvanic series (Figure 6): 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.

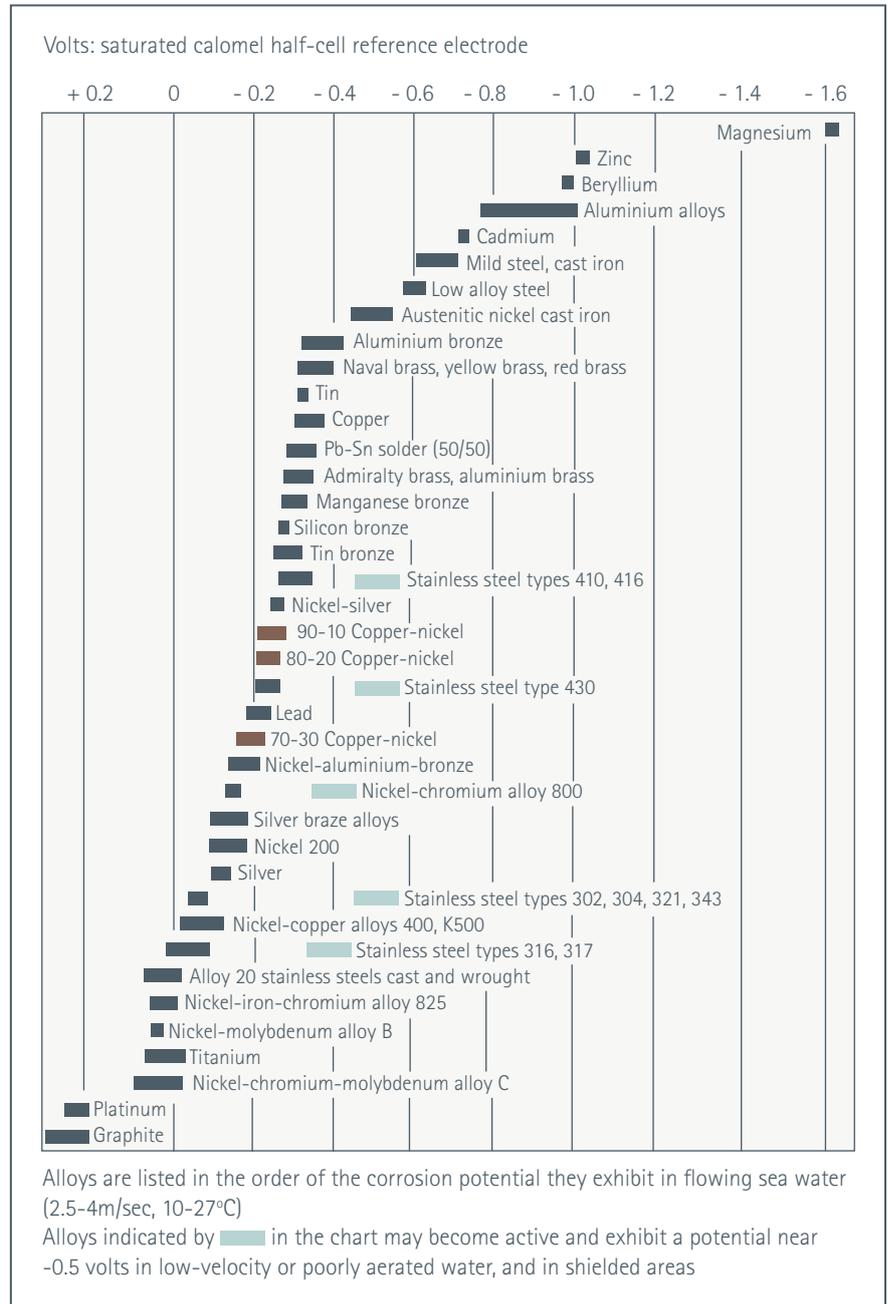


Figure 6 – Galvanic series

11.5 Handling Sulphides

Sulphides are present in polluted water either from industrial effluent or when the water conditions support the growth of sulphate reducing bacteria. They can also be produced in stagnant conditions by decomposition of organic matter. Sulphides can interfere with surface film formation on copper-nickel alloys, 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. Exposure to sulphides should be restricted wherever possible and particularly during the first few months of contact with seawater while the normal protective oxide film is maturing.

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

For condensers and piping systems, fitting out and commissioning are the likeliest stages for sulphides to be a hindrance. 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. Low levels of chlorination have also been found to mitigate corrosion attack in sulphide polluted seawater. Chlorination treatment and ferrous sulphate treatment should be staggered if both are used in the same system as there is a tendency for a precipitated floc to form if they are dosed at the same time.

An alternative method of adding ferrous ions 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 dimethylthiocarbamate has been used by the British and German navies. The UK Ministry of Defence have addressed preconditioning in 'Protection of Seawater System Pipework and Heat Exchanger Tubes in HM Surface Ships and Submarines' Defence Standard 02-781, Issue 2. It is also relevant to other marine industries.

After brief exposure to sulphides during normal operation, clean water should be restored as soon as possible. Normal shipping harbour turn around 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.



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

12.0 Biofouling Resistance

Copper-nickel's natural properties have a high resistance to marine 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 colonisation of macrofoulers. 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 removed by a light scraping.



Exposure panels (left to right in above picture): 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 macrofouling 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

13.0 Checklist

For the best resistance to corrosion and biofouling:

- Source copper-nickel from a reputable supplier and to international standards
- Maintain a high level of cleanliness during the fabrication of copper-nickels
- Use 70-30 copper nickel consumables for similar welds in 90-10 and 70-30 copper nickel
- Use 65% nickel-copper consumables for copper-nickel-steel dissimilar welds
- Ensure maximum velocity limits for the alloys are not exceeded
- Avoid velocity raisers - eg sharp angled bends in pipe systems
- Avoid use of polluted water during commissioning
- Add ferrous sulphate to enhance the protective film formation if extra safeguard required
- Electrically insulate copper-nickels from less noble alloys when highest resistance to biofouling is required.



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

14.0 Bibliography

14.1 General

Copper-nickel Alloys: Properties and Applications. NiDI/CDA Publication TN 30. 1982

90-10 Copper-nickel. CDA Publication No 118. 1997

90/10 and 70/30 Alloys Technical Data. CDA Publication TN 31. 1982

Guidelines for the Use of Copper Alloys in Seawater. A Tuthill. Nickel Institute Publication 12003

The Application of Copper-nickel Alloys in Marine Systems. Technical report (compendium) available from CDA Inc

The Corrosion of Copper and its Alloys: A Practical Guide for Engineers. Roger Francis. NACE International. 2010

Copper Alloys for Marine Environments. CDA Publication No 206. 2012

The Corrosion Performance of Metals for the Marine Environment: A Basic Guide. Edited by C Powell and R Francis, European Federation of Corrosion/NACE. Maney Publishing. 2012

Many additional papers are also downloadable from www.coppernickel.org web pages.

14.2 Fabrication

Joining Copper-nickel Alloys. R E Avery. CDA Inc Seminar Technical Report 7044-1919. The Application of Copper-nickel Alloys in Marine Systems. 1992

Brazed Copper-nickel Piping Systems. CDA Inc Application Data Sheet 701/5

Fabrication of Copper-nickel Alloys for Offshore Applications.

D E Jordan, C Powell. Welding in Maritime Engineering. October 1998. Croatia

Machining Brass, Copper and its Alloys. CDA Publication TN 44. 1992

Recommended Machining Parameters for Copper and Copper Alloys, DKI Monograph i.18. 2010

Pipelines of Copper-nickel Alloys-Part 2. Basic Principles for Design, Fabrication and Testing. DIN 85004

Welding Copper-nickel Clad Steel. CDA Inc Application Data Sheet

Copper Advantage: Guide to Working with Copper and Copper Alloys. Copper Development Association Inc Publication. 2010.

14.3 Piping Systems, Heat Exchangers and Condensers

Protection of Seawater System Pipework and Heat Exchanger Tubes in HM Surface Ships and Submarines. DEF Stan 02-781. Issue 2. UK MoD

The Selection of Materials for Seawater Cooling Systems - A Practical Guide for Engineers. R Francis. NACE International. 2006

The Design and Installation of 90-10 Copper-nickel Seawater Piping Systems. Nickel Institute Publication 11007

Heat Exchanger and Piping Systems from Copper Alloys - Commissioning, Operating and Shutdown. M Jasner et al. KME publication. 1998

Successful Welding of Tubes to Tubesheets. D Reynolds, J Kratz, J Kiefer. 2nd Symposium of Shell and Tube Heat Exchangers. Houston. September 1981

14.4 Offshore Sheathing

Review of Splash Zone Corrosion and Biofouling of C70600 Sheathed Steel during 20 Years Exposure. C Powell and H Michels. Eurocorr 2006. Maastricht

Metallic Coatings for Corrosion Control for Marine Structures. D Peters, H Michels, C Powell. International Workshop on Control for Marine Structures and Pipelines. Galveston 1999

14.5 Boat Hulls

The Asperida, a Copper-nickel Sailboat after more than Thirty Years in Seawater. H Michels and K Geremia. Paper 5238 Corrosion 2005 NACE International

Corrosion and Biofouling Protection of Ship Hulls Using Copper-nickel. Proceedings of International Conference on Marine Corrosion Prevention - A Re-appraisal for the Next Decade. C Powell. October 1994. London. Royal Institute of Naval Architects

Copper-nickel Sheathing Costing Study - Phase 3. MARAD Report 770 87026. US Dept of Transportation. August 1987

CA 706 Copper-nickel Alloy Hulls: The Copper Mariner's Experience and Economics. Monzillo, Thiele and Tuthill. The Society of Naval Architects and Marine Engineers. 1976

Use of Copper-nickel Cladding on Ships and Boat Hulls. CDA Publication TN 36. 1985

14.6 Biofouling

Long Term Exposure Trials Evaluating the Biofouling and Corrosion Resistance of Copper-nickel Alloy Sheathing Materials. S Campbell and C Powell. 12th International Congress on Marine Corrosion and Fouling. July 2004. University of Southampton

Biofouling Resistance of Cupronickel - Basics and Experience.

W Schleich and K Steinkamp. Stainless Steel World 2003 Conference. Maastricht. November 2003

Preventing Biofouling with Copper Alloys. CDA Publication 157. 2002

Seawater Corrosion Resistance of 90-10 and 70-30 Copper-nickel - 14 year Exposures. K Efir and Anderson. Material Performance. November 1975

The Interrelation of Corrosion and Fouling of Materials in Seawater. K Efir. NACE Corrosion-75. Toronto. 1975

Controlling Biofouling on Ferry Hulls with Copper-nickel. L Boulton, C Powell. 10th International Congress on Marine Corrosion and Fouling. Melbourne 1999

Many of these papers are available to download from the following websites:

www.copperalliance.org.uk

www.copper.org

www.coppernickel.org

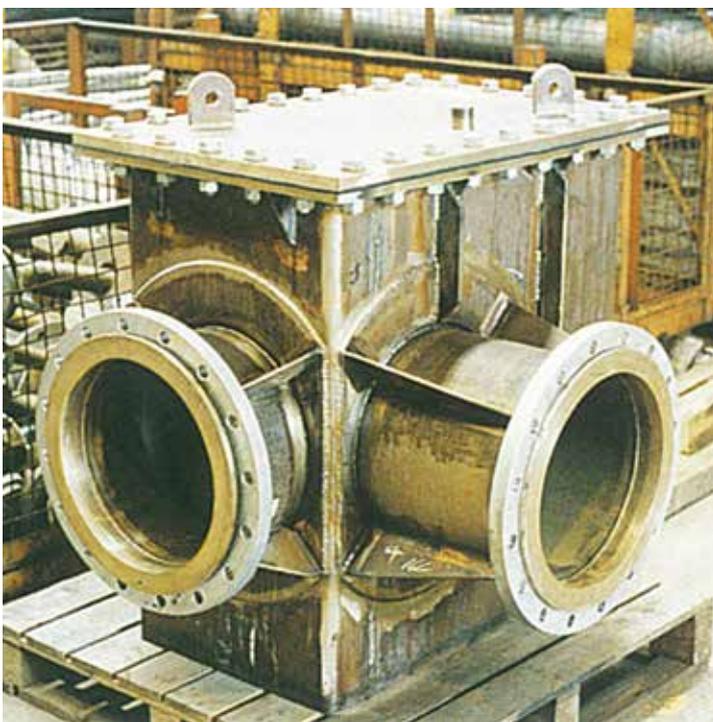
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90-10 copper-nickel welded fabrication with flange connections





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