Copper-Nickel Cladding for Offshore Structures

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Copper Development Association

Copper Development Association is a non-trading organisation sponsored by the copper producers and fabricators to encourage the use of copper and copper alloys and to promote their correct and efficient application. Its services, which include the provision of technical advice and information, are available to those interested in the utilisation of copper in all its aspects. The Association also provides a link between research and user industries and maintains close contact with other copper development associations throughout the world.

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Introduction

The designers of structures to be exposed to the open sea must consider many aspects of the harsh environment in order to ensure a safe working life.

Sea water is corrosive to most of the usual materials of construction and due allowances must be made for its action at, below, and above the normal waterline levels. Water currents bring marine life to colonise structures; the weight of seaweed and molluscs which is added can have a serious effect on design stresses. Wave forces can be very high indeed on occasions and their maximum effect must be allowed for.

When the gas platforms were being designed for Morecambe Bay it was realised that conditions would be more demanding even than those in the North Sea. To obtain an economic life the steel legs of the platforms had to be protected from the corrosion abrasion and biofouling caused by the sea.

Cladding these legs with 90/10 copper-nickel alloy sheet is proving to be the ideal choice for this purpose.

Morecambe Bay Gas Platform with,copper-nickel alloy cladding in splash zone.
[photo: British Gas Corporation]

The Environment

In Morecambe Bay the gas platforms are in a severe environment. Besides being exposed to the prevailing westerly winds the structures have to withstand tidal forces exaggerated by the presence of the river estuary. The tidal height range is 11 metres and at times the sea water contains a high proportion of abrasive suspended solids. The fact that the site is subject to some influence from the Gulf Stream means that the growth of marine biofouling can be very rapid.

The corrosion rate of steel platform legs in the splash zone is typically ten times greater than that above or below this level. This is because of the high levels of oxygen available to corrode the wet steel, aggravated by abrasion by wave action which exposes fresh metal surfaces. Up to 5mm/year metal corrosion rates for bare steel have been reported.

To counteract this it is normal practice to increase steel thickness to provide a corrosion allowance suitable for the expected life of the platform. In the North Sea, this extra thickness is of the order of 12mm which adds substantially to the overall weight and cost of the structure. Periodic inspection is needed to monitor the condition of the steel. The repainting of the structure is difficult and unless it is removed back to a shore base the results may not be satisfactory.

Since paint systems, or cladding with other organic coatings such as neoprene, cannot be guaranteed to remain intact, certifying authorities still require the same amount of sacrificial steel and the consequential increased weight.

Cladding the steel with copper-nickel gave confidence that corrosion rates would be minimal and that the life of the platforms would equal the economic life of the gas field, possibly up to forty years.

The cost savings in the use of copper-nickel for splash zone corrosion protection are shown in Table 1. [2]

Table 1 - ***Summary comparison of splash zone corrosion protection costs for 15-year life (all costs in £1 million). Copper-nickel cladding can save approximately £1 million in the cost of a typical jacket. For longer life spans (40 years predicted) the advantages of using it are even greater.***

Costs	**Paint Systems**	**Neoprene Jacket**	**Cladding with Copper-Nickel**
Capital cost (extra steel)	2.3	2.3	0.5
Capital cost (paint) (neoprene wrap) (fabrication)	0.1	0.3	0.45
Maintenance cost (NPV at 10% pa)	2.4	unknown	0.15
Extra weight (tons)	660	660	180

Previous Experience with Copper-Nickel

In the early years of exploitation of North Sea Oil, several of the platforms were equipped with steel sea water service pipes for cooling water and fire-fighting mains. The very high costs of replacing these as they failed by corrosion proved the widsom of the use of copper-nickel, which is far more reliable and gives benefits that far outweigh the higher first-cost.

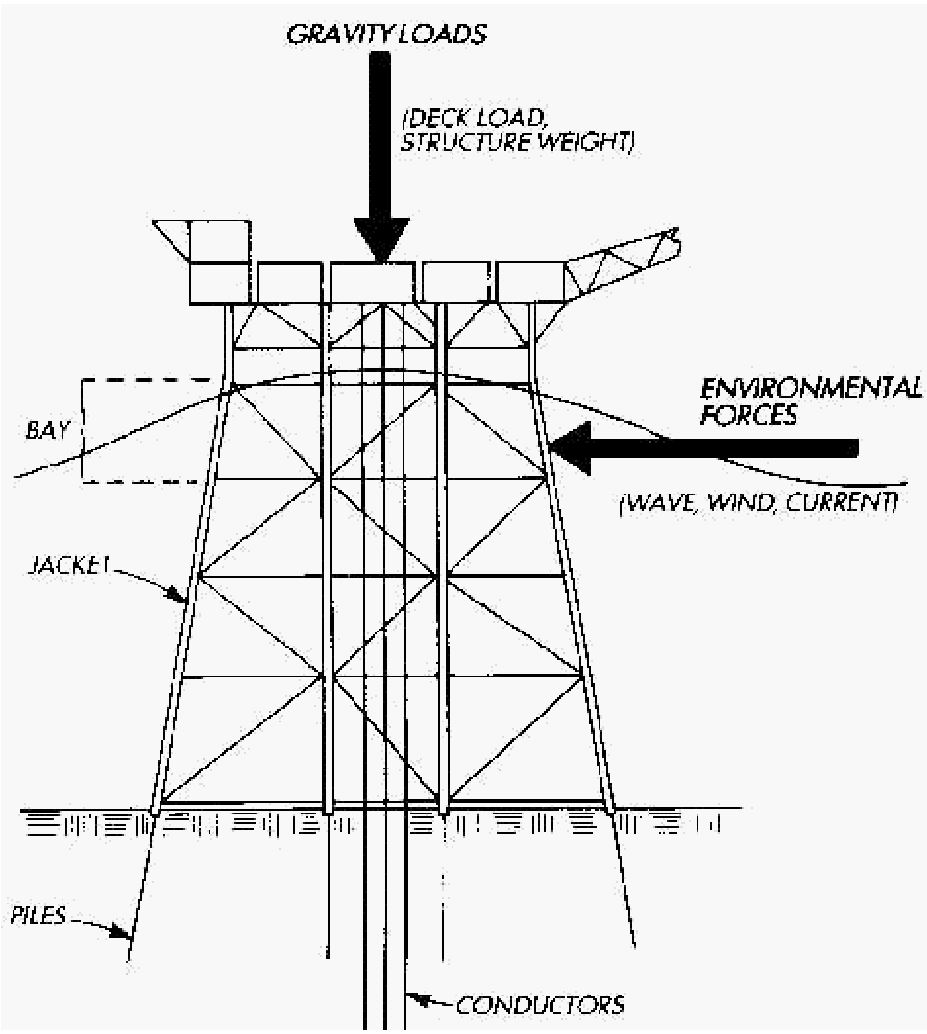
Copper-nickels have long been used for similar pipeline services in ships and have also been established for many years as preferred materials for many desalination plants, sea water cooled heat exchanger and hydraulic pipeline applications.

The use of copper-nickel cladding for ships' hulls also demonstrates the value of the material's combined attributes of resistance to corrosion and to marine biofouling. Many small vessels have been built using copper-nickel plating or copper-nickel clad steel plating. There have also been many successful trials of cladding on the sides and rudders of large vessels subject to severe service conditions ranging from the impact and abrasion of Arctic ice or the sides of the Panama Canal, to tropical waters that normally give rise to heavy fouling. The economics of reduced hull maintenance and improved fuel economy have been well demonstrated. [3,4]

Economic Evaluation

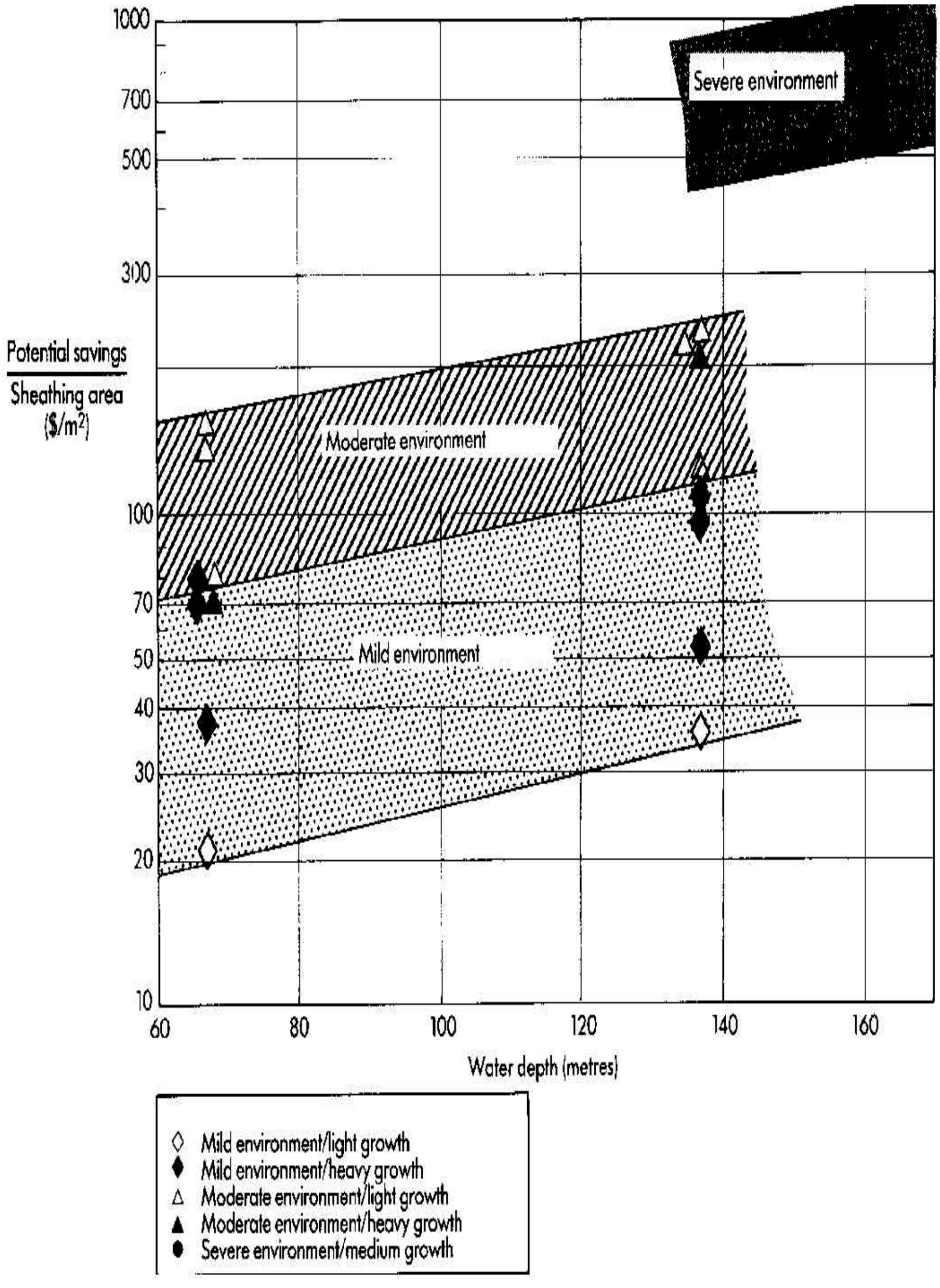
A recent study [5] has evaluated the potential cost savings resulting from the use on offshore platforms of copper-nickel sheathing, insulated from the steel structure, taking into account the reduction in design requirements to withstand marine growth loadings (Figure 1).

Figure 1 – Simplified diagram of forces acting on offshore structures as considered by Barger et al.



The investigation examined platforms in three water depths for environmental conditions ranging from mild to severe and for marine growth ranging from light to heavy. Using computer-aided design techniques conceptual platform designs were developed to determine the potential savings in jacket and pile steel that would result from the use of copper-nickel sheathings. (Figure 2).

Figure 2 – Potential savings per area of sheathing for various environments and water depths



In severe weather environments like the North Sea (design wave height of 90 ft), copper-nickel sheathing would reduce the total platform and pile cost by about 9%, corresponding to roughly $8.7 million in potential savings in material and fabrication cost. In moderate environments, typical of the Gulf of Mexico (design wave height of 71 ft). the weight savings for the extreme case amounted to about $0.9m, or about 6% of the total platform cost. Even mild environments, such as Malaysia (design wave height of 34 ft), weight reductions would save up to about $0.5m, or about 4% of the reference platform cost. (These cost estimates are based on typical 1983 material and fabrication rates for the North Sea, Malaysia and the Gulf of Mexico).

The economic incentives for the use of copper-nickel sheathing increase in deeper water and in areas subject to heavy marine growth, and may extend beyond savings in material and fabrication costs. For example, in some locations operators choose periodically to remove marine growth from their platforms rather than design the structures for the ultimate growth levels that might occur during the service life of the platform. In these cases, such as in offshore California, copper-nickel sheathing could reduce operating costs by as much as $100,000 per platform each year if the need for periodic cleaning is significantly reduced or eliminated. Owing to the much more severe conditions in the North Sea the savings from elimination of cleaning the larger structures could be over ten times greater.

The reduced wave loading achieved from attaching the sheathing contributes to potential cost-savings in four other areas:

1. Offshore pile installation time could be saved. For instance in severe environments such as the North Sea, the lighter structures that sheathing permits could reduce the required number of piles by four. Four days installation costs would be saved, amounting to about $1.2 million in the North Sea.
2. Copper-nickel sheathing provides cost savings by shielding the steel from corrosive attack so allowing the extra thickness added as a corrosion allowance to be eliminated. Savings would also come from a reduction in the number of anodes needed to protect the smaller area of unclad steel.
3. Sheathing could result in lower stresses in the lighter structure enabling cost savings to be realised by reducing the required thickness of fatigue-prone joints, saving joint material costs.
4. Reducing joint thickness would also help to reduce, or eliminate, the need for the post-weld heat treatment that has to be applied to stress-relieve thicker joints.

At present structures are fitted with cathodic corrosion protection systems in the form of either sacrificial anodes or impressed current equipment. Where fitted the anodes are usually of zinc and sized to last the expected life of the structure. They are themselves heavy and require suitable extra supports. Impressed current protection systems require continual maintenance to ensure effectiveness.

Ideally, offshore structures should be fully protected from both corrosion and marine biofouling right down to the sea bed by copper-nickel sheathing. An obstacle to the adoption of this practice is the existing need to examine the nodes at regular intervals for the possible onset of fatigue cracks. Non-destructive testing techniques cannot yet be used through sheathings and more service experience will be required before it is allowable to dispense with these costly routine inspections.

Offshore Structure Sheathing/Cladding Techniques

When considering covering steel with copper-nickel, five types of technique are possible:

Direct Welding: Nominally 4 mm thick 90/10 copper-nickel sheet is welded directly on to the structure. The copper-nickel sheet must be pre-rolled to the appropriate radius for fitting around the tubular members.

Welding on to steel bands: Steel bands of 6 mm thickness are welded by conventional means on to the structure. The joints between adjacent copper-nickel sheets coincide with the steel bands and the joining welds are made on to them. This technique has been advocated by those who consider that there is a risk of unacceptable copper penetration of the structural steel during welding. However, costs of welding are increased and experience suggests that this precaution is not necessary.

Insulated system using cement grout: Neoprene pads 100 mm square by 25 mm thick are mounted round the tubular steel structure at about 500 mm intervals. Over this is welded the copper-nickel sheet jacket. A cement grout is pumped into the 25 mm annular gap.

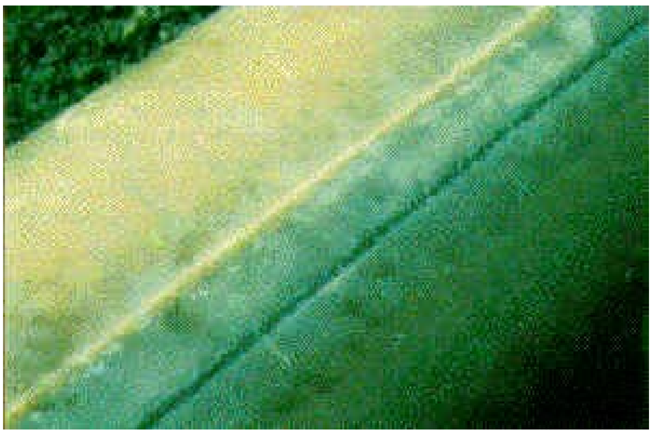
Insulated system using epoxy grout: This is similar to the previous system but uses epoxy cement grout. Because this is more readily pumped, the annular cavity can be reduced from 25 to 12 mm. This reduces weight significantly.

The cost relationships between these methods are shown in Table 2.

Table 2 – Cost relationships between four cladding techniques, taking direct welding as unity [1]

Technique	**Comparative Cost**
Direct welding	1
Welding on to steel bands	1.2
Cement grouting	1.1
Epoxy grouting	1.3

The fifth technique is to *fabricate structures directly from steel sheet clad with copper-nickel before hot rolling.*



Close-up of copper-nickel alloy cladding - overlapped and welded joint
(Photo: International Copper Research Association)

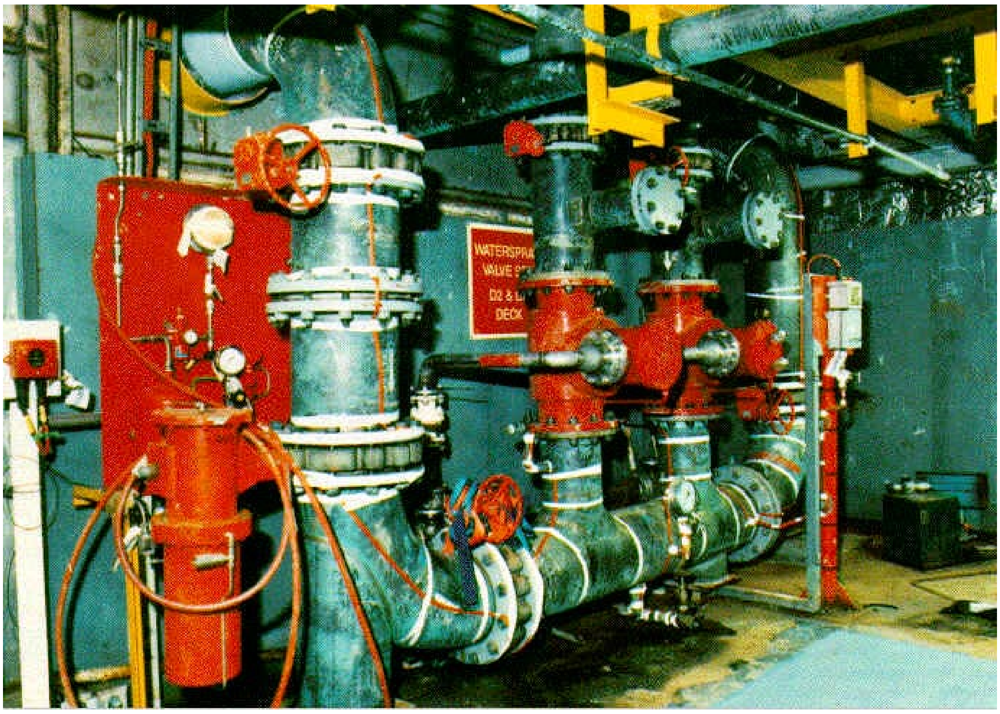
The selection of attachment technique depends on the design objectives. If the whole structure were to be sheathed, complete corrosion and biofouling protection would be obtained, there would be no galvanic effects, no cathodic protection system would be needed, and the cheapest attachment technique (direct welding) could be used. However, as indicated, there are at present reservations about sheathing of node areas. The current approach, therefore, is to sheath the areas where heaviest corrosion and fouling occurs, i.e. the splash and tidal zones, using cathodic protection systems for the lower, continuously immersed ports of the steel structure. If direct attachment is used, cathodic protection of the immersed areas of copper-nickel would be expected to result in loss of resistance to biofouling. However, tests show that the welded-on copper-nickel sheathing gives no more drain (in fact, rather less) on the cathodic protection system than when there is unsheathed steel in the splash/tidal zone. Full corrosion and biofouling protection (with a reduced load on the cathodic protection system) is obtained with an electrically insulated copper-nickel sheathing system, and these are the techniques that should show greatest economic benefits.[5]

For the Morecambe Bay project the choice made was to weld preformed copper-nickel plate directly on to the steel in a zone from five metres above the maximum high tide level to two metres below minimum low tide level. Performance to date is satisfactory. Where visible the copper-nickel retains a bright polished appearance.

The Structure of Surface Films on Copper-Nickel

The 90/10 copper-nickel alloy develops a protective film that is resistant to both corrosion and marine biofouling, making it suitable for many marine applications.

The characteristics of this film are complex and only now becoming understood [7]. It develops quickly in natural oxygenated sea water at ambient temperatures. Controlled additions of iron and manganese to the alloys have been shown to be essential for good resistance to impingement attack (corrosion-erosion) in sea water.[8].



Copper-nickel alloy pipework on Morecambe Bay Gas Platform.
[photo British Gas Corporation]

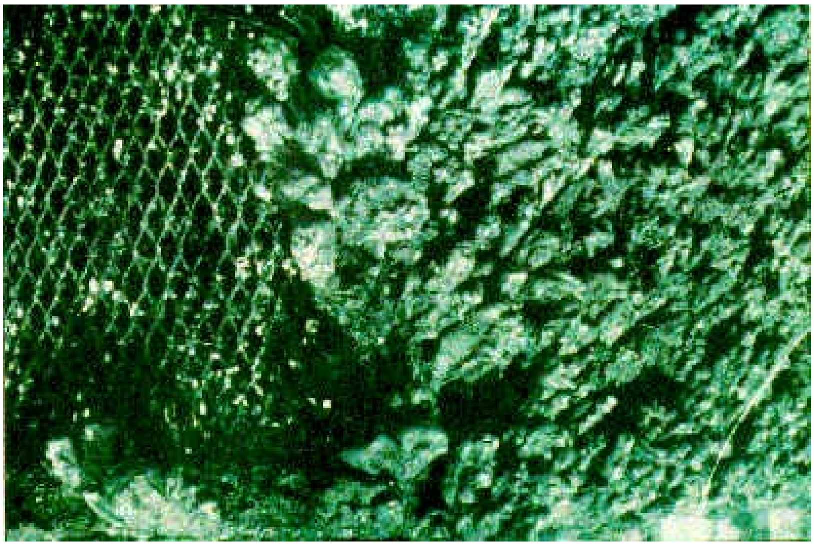
Following their extensive work on the surface chemistry of 90/10 copper-nickel, Castle and his co-workers [7] described three layers forming on the metal during exposure to quiescent sea water. Firstly, there was an outer layer, a deposit of the basic copper chloride, paratacamite. This layer was markedly crystalline and would only be deposited in quiescent conditions. Hence it is not usually found on samples removed from operating equipment. The middle layer contained both copper and a marked enrichment of either one or both of nickel and iron, as oxides, chlorides, or more complex minerals. This layer was porous, varied considerably in texture and was easily rubbed away. It contained organic material which may influence the cohesion and strength which it exhibits. Its high copper content is presumably responsible for the good resistance to marine biofouling by most organisms. The fact that it is fairly easily rubbed off accounts for the early sloughing off of any fouling that may tend to deposit during quiescent periods.

The inner layer was thin and could only be detected when the outer layers were stripped away with adhesive tape. It contained copper and some oxygen and a high concentration of chloride. Cuprous chloride was identified and appeared to be the essential component of this inner layer.

As these layers develop over the first days of exposure the corrosion rate of the material decreases due to polarisation of both anodic and cathodic reactions. Cathodic inhibition is not destroyed when the outer layers are stripped away, being maintained by the thin cuprous chloride layer, and it is this behaviour that gives the material good resistance to general or localised corrosion. The cathodic inhibition can be reduced in anaerobic conditions in the presence of organic matter, and this effect may account for occasional cases of higher corrosion rates when adverse initial environmental conditions are encountered.

The layers described above give good corrosion resistance in static or slowly moving sea water but are readily removed under turbulent conditions. For resistance to such conditions an outer iron-rich deposit is needed and this is normally found on samples from service. This aspect is still under investigation.

Such protective films are effective in pipeline applications with design velocities of up to 3.5 m/sec (in pipes over 100 mm diameter), which allows a suitable safety margin for the much higher local velocities and turbulence caused by valves, reducers, bends or other pipeline features. In use in open sea condifions on ships hulls, satisfactory performance has been recorded with regular service speeds of 24 kts (over 12 m/sec).



Comparison of unfouled copper-nickel alloy mesh (left) with adjacent heavily fouled galvanised steel mesh after exposure in seawater [photo: Intemational Copper Research Association]

*Table 3 - **Specifications for Wrought 90/10 Copper Nickel***

	Composition - per cent											
Designation	**Copper**	**Nickel**	**Iron**	**Manganese**	**Lead (max)**	**Sulphur (max)**	**Silicon (max)**	**Carbon**	**Niobium**	**Tin**	**Zinc**	**Total Impurities (max)**
ISO CuNi10FeMn	Rem (Rest)	9.0-11.0	1.2-2.0	0.5-1.0	0.03 [3]	0.05	-	0.05	-	0.02	0.5	0.1 [4]
BS CN102	Rem (Rest)	10.0-11.0	1.00-2.00	0.50-1.00	0.01	0.05	-	0.05	-	-	-	0.30
ASTM C96200	84.5-87.0	9.0-11.0	1.0-1.8	1.5 max	0.03 [1]	-	0.30	0.10	1.0	-	-	-
DIN CuNi10Fe1Mn	Rem (Rest)	9.0-11.0	1.0-2.0	0.5-1.0	0.03	0.05 [2]	-	0.05	-	-	0.5	0.3

1. For welding grades lead may not exceed 0.01%
2. For welding grades sulphur and phosphorus may not exceed 0.02 %
3. Sn + Pb max. 0.05%
4. Total other impurities

Table 4 – Typical mechanical properties of 90/10 copper-nickel [6]. Exact values vary with composition, size, extent of cold work and annealing treatments).

Form	Condition	0.2% Proof Stress N/mm2	Tensile Strength N/mm2	Elongation on 5.65√So per cent	Hardness HV	Shear Strength N/mm2
Plate and sheet	Annealed	120	320	42	85	250
	Hot rolled	140-190				
Sheet	Cold rolled	380	420	12	125	190
Tube	Annealed	140	320	40	85	250
	Cold drawn (hard)	460	540	13	165	360
	Temper annealed	190-320	360-430	38-30	115-140	280-320

Note: The heat affected zone of welded material will have properties similar to those of the 'annealed' condition.

Table 5 – Availability of wrought 90/10 copper-nickel

Form	Thickness(mm)	Outside Diameter (mm)	Width (mm)	Length (mm)
Plate and Sheet				
Cold-rolled	0.5 - 6		2500	8000
Hot-rolled	4 - 140		3000	8000
Tubes-seamless				
Pipeline	0.5 - 15	8 - 419		
Condenser	0.75 - 2	8 - 35		
Coiled	0.5 - 3	6 - 22		
Longitudinally welded	2 - 10	270 - 1600		
Forgings	by arrangement			
Wire		0.01 - 6		
Rod and Section		6 - 180		

References

1. Wildsmith, G. "Copper Alloys for sea water systems and splash zone protection". Paper to Norges Ingeniørorganisasjon, Conference on Corrosion Control, April 1985.
2. Callcut, VA. "Expanding Markets for 90/10 copper-nickel alloys" Metals & Materials 1(1985)8, 489-494, (after Carruthers, R. "The use of copper-nickel as a splash-zone cladding". Copper Alloys in Marine Environments Seminar 1985, paper 6, Copper Development Association).
3. Manzolillo, J L, Thiele, E W & Tuthill, A H. "Copper-nickel alloy hulls - the Copper Mariners' experiences & economics" Society of Naval Architects & Marine Engineers Conference. New York, November 1976.
4. Pircher, H and Ruhland, B. "Use of copper-nickel cladding on ship and boat hulls". Copper Alloys in Marine Environments Seminar 1985, paper 5, Copper Development Association.
5. Barger W R, Downer, L D, Brown, J E and Gaul, T R. "Economic evaluation - use of copper-nickel for sheathing of offshore structures". INCRA Project No. 359, Final Report, 1984, Intemational Copper Research Association, 25 pp.
6. "Copper-nickel 90/10 & 70/30 alloys—Technical Data". Copper Development Association, TN 31,1982.
7. Castle, J E and Parvizi, M S. "Protective surface film characteristics of copper alloys in sea water". Copper in Marine Environments Seminar 1985, paper 10, Copper Development Association.
8. Bailey, G L. "Copper-nickel-iron alloys resistant to sea water corrosion". J. Inst. Met. 1951: 79, 243-292.

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