REVIEW OF SPLASH ZONE CORROSION AND BIOFOULING OF C70600 SHEATHED STEEL DURING 20 YEARS EXPOSURE

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Abstract

In 1984, 90-10 Cu-Ni (C70600) was installed for splash zone protection on the legs of Stage 1 of the Morecambe Gas Field platforms in the Irish Sea. To examine the performance of Cu-Ni in close detail, two studies were initiated by the LaQue Center for Corrosion Technology in North Carolina, USA.

The first commenced in November 1983 with a series of 26 test pilings exposed to Banks Channel at Wrightsville Beach. Ten had Cu-Ni welded directly to steel, seven had the sheathing insulated from the steel with concrete and seven were bare steel. Some possessed cathodic protection and others did not. Two pilings were clad with 65%Ni-Cu alloy 400(N04400) and cathodically protected. Shortly afterwards, the programme was extended to include 14 pilings with a layer of butyl rubber acting as insulator between the steel and Cu-Ni sheathing. The pilings were systematically removed and examined over the next ten years.

The second set of trials began in 1987 and involved six pilings, slightly offshore from the breaker line at Kure Beach fishing pier. Three were positioned on the north side of the pier and three on the south. Each side involved a plain steel control, Cu-Ni sheathing welded to the steel and Cu-Ni sheathing insulated from the steel. All had cathodic protection applied on the steel below the water line.

Both sites suffered the ravages of extreme weather including hurricanes to which the area is prone, but the piles survived. Now, after 20 and 16 years exposure respectively, the test sites are being abandoned and final long-term investigations have been carried out. This paper reviews the testing and findings of both sites over these years, particularly with regard to the corrosion and biofouling behaviour of Cu-Ni.

1. Introduction

The use of 65%Ni-Cu alloy 400 (N04400) for splash zone sheathing on offshore structures dates back over 50 years. In the 1980s, it was recognised that 90-10 Cu-Ni could offer a valid alternative in terms of corrosion resistance and would have an added potential advantage in that it could also provide resistance to macrofouling. Stage 1 of the Morecambe Field was the first major project to make use of the Cu-Ni sheathing concept although in this case the prime reason was to make use of its corrosion resistance. The copper industry wished to examine the performance of sheathing more closely and initiated long term exposure trials at two sites, co-ordinated by the LaQue Center for Corrosion Technology in North Carolina, USA, examining various types of attachments to steel pilings which would evaluate both corrosion and biofouling behaviour. Despite the ravages of extreme weather including hurricanes to which the area is prone, the pilings survived. Now, after 20 and 16 years exposure respectively, the test sites are being abandoned and final long-term investigations have been carried out. The purpose of this review is to record the findings and compare them to the behaviour of the sheathing still in service in the Morecambe Field.

2. Splash Zone Corrosion and the Metal Sheathing Concept

The intensity of corrosion of an unprotected steel structure in seawater varies markedly with position relative to the mean high and low tide level as shown in Figure 1.

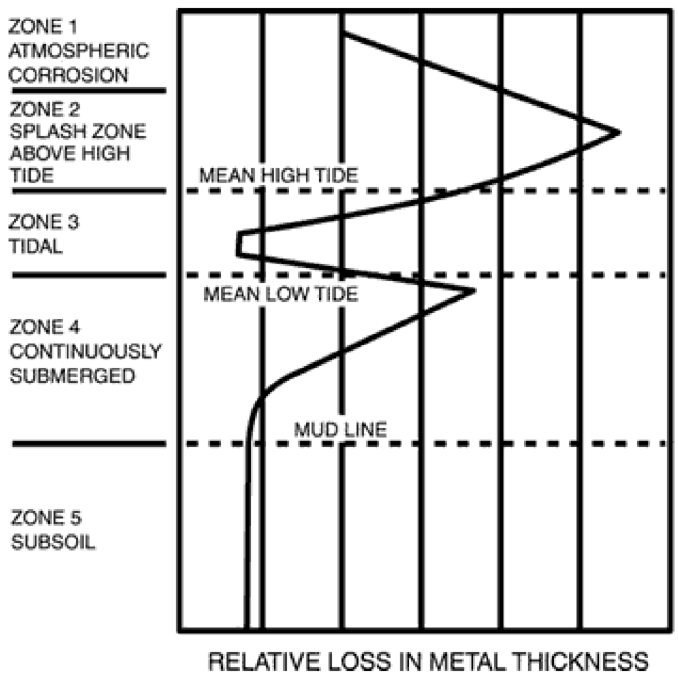


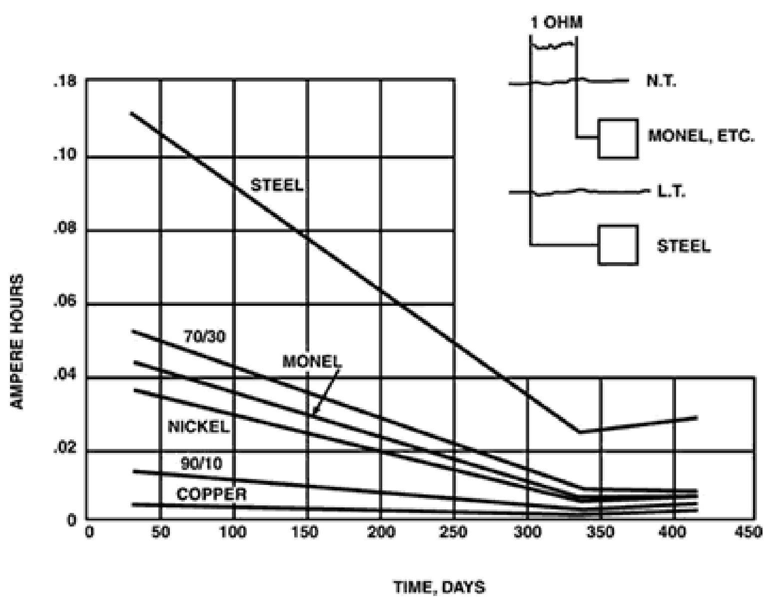
Figure1**.** Profile of the Thickness Loss Resulting from Corrosion of an Unprotected Steel Structure in Seawater

The spray and splash zone above the mean high tide level is the most severely attacked region due to continuous contact with highly aerated sea water and the erosive effects of spray, waves and tidal actions. Corrosion rates as high as 0.9 mm/y at Cook Inlet, Alaska, and 1.4 mm/y in the Gulf of Mexico have been reported. Cathodic protection in this area is ineffective because of lack of continuous contact with the seawater, the electrolyte, and thus no current flows for much of the time. Corrosion rates of bare steel pilings are often also very high at a position just below mean low tide in a region that is very anodic relative to the tidal zone, due to powerful differential aeration cells which form in the well aerated tidal region.

Protection of a steel structure can be achieved by various means; each corrosion zone being separately considered. Three generally accepted methods are cathodic protection, painting or coating, and sheathing. Metal sheathing has proved to be a very successful approach when applied in the region through the splash/spray zone to a short distance below the tidal zone. As early as 1949, 65% Ni-Cu (Alloy 400) was utilised on an offshore platform in the Gulf of Mexico off the Louisiana coast (1) and for the last 50 years the alloy has been applied to the legs and risers of many offshore structures with various studies assessed to explain its good performance(2,3,4,5,6,7,8).

In early trials of 65Ni-Cu (Alloy 400) welded directly to the steel, it was assumed that corrosion of the anodic steel below the tidal zone would be accelerated because it is in direct contact with the more noble sheathing alloy. A number of experiments were conducted at the LaQue Center to investigate this possibility (4). On the contrary, steel below the tidal zone was found to be cathodic relative to the noble alloy sheathing material, since the sheathing alloy became polarized to the potential of the adjacent steel below. Hence the submerged steel below the sheathed piling corroded at a lower rate than the submerged steel on an unsheathed bare steel piling because the resulting galvanic current between the sheathed tidal zone and the submerged steel below it is lower.

This conclusion is confirmed by the results of galvanic corrosion tests conducted to determine the effects on submerged steel coupled to other alloys in the tidal zone (3) as shown in Figure 2.



Fiigure 2. Total Current per Tide vs. Time between Plates in a Simulated Piling Test.
(N.B. The trade name MONEL refers to alloy 400)

Plates of the alloys placed in the tidal zone were coupled to submerged steel plates, and the total current per tide was measured periodically over the 14-months of exposure. Current decreased with time, but the results demonstrated clearly that the most severe galvanic couple is steel to steel. Although the potential difference between the noble alloy-to-steel couples is significantly greater than the potential difference between two steel panels, the rapid and nearly complete polarization of the noble metal resulted in a lower galvanic current. Since then, the International Copper Research Association (now the International Copper Association) conducted several research programs clarifying and elaborating on these earlier findings(5,6,7). In summary, steel under water corrodes less when in contact with noble metals in the tidal zone than when coupled to another panel of steel in the tidal zone.

3. 90-10 Copper-Nickel as a Sheathing Alloy

90-10 Cu-Ni (C70600) is an established alloy for seawater systems and recognised for its unique combination of high resistance to corrosion and macrofouling(9,10.11). As such, it has been considered as a potential boat hull material and other applications where the two properties could be used(12). The alloy is particularly attractive for marine structure sheathing because it can provide corrosion protection and at the same time resists the build up of the thick biofouling mass that degrades the performance, structural integrity, and even the safety of the structure. In addition, it can reduce maintenance costs by minimizing the need to remove biofouling on a regular basis as well as eliminating the need for periodic re-application of antifouling paints and coatings(8).

Maximum resistance to biofouling relies on 90-10 Cu-Ni being freely exposed and not galvanically or cathodically protected by less noble materials(11). It is thought that this allows the availability of free copper ions in the surface film to inhibit the growth of macrofouling (grasses and hard shell growths) although some microfouling(slimes) will colonise. Attachment of the sheathing material to the steel structure by welding or mechanical fasteners will result in cathodic polarization of the sheath material and a reduction in the antifouling capability of the 90-10 Cu-Ni alloy. Therefore it is necessary to electrically insulate the sheath from the steel jacket members to gain the full advantage of the biofouling resistance properties of the alloy. Electrical insulation can be achieved by pumping cement or an epoxy into the annular space between the component and the sheath or, more simply, by use of an elastomer or rubber-base insulator.

For straight splash zone corrosion protection on offshore structures, the Cu-Ni is usually welded into position. Welded splash zone sheathing on steel offshore platforms in 90-10 Cu-Ni should at least span from below mean tide level to well into the atmospheric zone. Potential galvanic corrosion on the adjacent steel is addressed by coating the more accessible top section with paint. Although trials discussed above indicate that accelerated corrosion at the submerged junction is not enhanced by the presence of the sheathing, the area will be protected by the cathodic protection system routinely applied to the structure(8). Sheet thicknesses of 3-5 mm would normally be recommended. The sheet is pre-formed to half cylinders and longitudinal joins are lapped so that the alloy is welded to itself. These require a 70-30 Cu-Ni weld consumable. Horizontal butt welds between sections can be made direct to the steel and are often a 3-bead method such that the cap experiences minimum dilution from the steel. 65Ni-Cu or appropriate Nickel consumables are required for the root runs on circumferential welds or fillet welds of Cu-Ni to steel to withstand the high levels of iron dilution from the steel. Where the steel has a rough surface or it is not considered appropriate to weld the alloy sheathing direct to the steel riser or structure, horizontal steel bands can initially be welded to the steel and the sheathing welded to the band. An outline of a typical cladding assembly is shown in Figure 3 with an indication of the types of joint involved and the weld procedure.

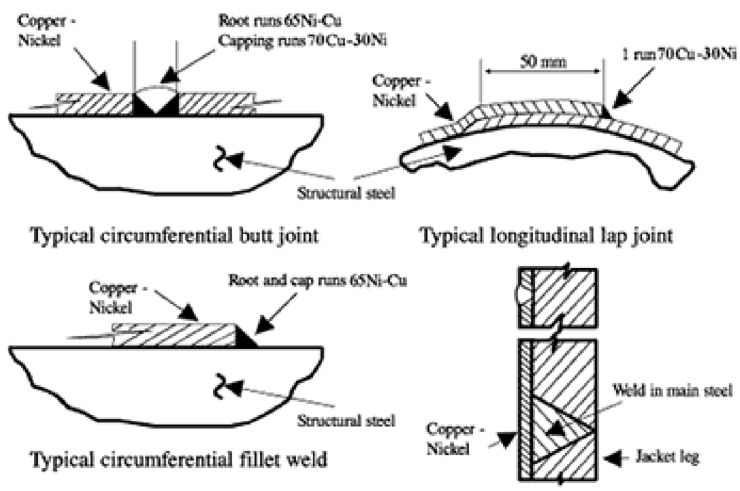


Figure 3. Typical joints for splash zone sheathing

The first major project for Cu-Ni splash zone sheathing was in 1984(13), used to cover legs on production and accommodation platforms, three drill platforms and a flare stack in the Morecambe Field, a major gas field in the Irish Sea. The sheathing was 4mm thick annealed sheet, welded directly to the steel and spanned +13m to -2m Lowest Astronomical Tide. Longitudinal overlap seams were specified using a MONEL 67 (70-30 Cu-Ni) consumable. Circumferential seams were welded direct to the steel using in this case the high nickel, Nickel 61, consumable with capping runs in MONEL 67. The legs were cathodically protected and so biofouling of the sheathing was anticipated.

Figure 4. Cu-Ni sheathing applied to a Morecambe Field Structure

4. Test programmes

4.1.1 Wrightsville Beach Exposures*(14)*

Long term exposure of Cu-Ni sheathed steel pilings, to assess the effectiveness of corrosion and biofouling resistance as well as the cathodic protection systems in several configurations as described below was sponsored by the International Copper Association and the Copper Development Association Inc. and carried out at the LaQue Center for Corrosion Technology in Wrightsville Beach, North Carolina. USA. ASTM Type A-36 steel pilings, 170 mm in diameter, were sheathed with 4.6 mm thick x 3 m long 90-10 Cu-Ni. Some Cu-Ni sheaths were directly welded to the steel, others were insulated from the steel with concrete or with 6 mm of a butyl rubber compound. Some pilings were cathodically protected with Galvalum III anodes while others remained unprotected. Pilings were removed after two, five and ten years of exposure in a natural flowing seawater channel for evaluation.

The test matrix of the steel pipings is shown in Table 1 and includes 90-10 Cu-Ni sheathed by three techniques (welded, concrete insulated and rubber insulated) as well as bare steel and 65% Ni-Cu alloy 400 sheathed controls. Apart from the alloy 400 and butyl rubber insulated Cu-Ni sheathing, which all had cathodically protected steel pilings, the remaining Cu-Ni and bare steel pilings were exposed with and without cathodic protection.

Sheathing Technique					Cathodic protection		Duration (years)				
C70600											Totals
Directly welded	Concrete insulated	Rubber insulated	Alloy 400	None	yes	no	2	5	10	20	
x					x		x	x	x	A	4
x						x	x	x			3
x(1)							x	x			3
	X				x		x	x	x	B	4
	x					x	x	x			3
			x		x				x	C	2
				X	x		x	x	x	D	4
				x		x	x	x			3
		x			x			x	x		14
										Total	40

(1) Intentional defect in sheathing

A: alloy C70600 directly attached to steel; B: alloy C70600 with concrete insulated steel; C: alloy 400 directly attached to steel; D Bare Steel(control)

Table1. Piling Test Matrix

The pilings were deployed in late 1983/early 1984 along the front of the wharf at the LaQue Center and removals were made after 2, 5 and 10 years.

Four piles remained in test for 20 years exposure until they were abandoned in place; one each with 90-10 Cu-Ni sheathing directly welded to steel, concrete insulated 90-10 Cu-Ni sheathing, 65Ni-Cu alloy 400 directly attached to steel with stainless steel fasteners and one bare steel(control); all under cathodic protection.

4.1.2 Preparation and fabrication of materials

A total of 40 pipes in steel to ASTM A-36 measuring 9.1m long by 170mm outside diameter and a wall thickness of 7mm were used. Sheet steel to a similar composition was cut to weld end caps to both ends of the pipe length to keep the internal surfaces dry for the length of their exposure. All the pipes were blasted to provide a uniform base condition prior to application of the sheathing.

Seven of these bare steel pilings were included as controls. Four of the pilings were cathodically protected and three were not.

4.6mm thick sheet in 90-10 Cu-Ni(C70600) was formed to the appropriate diameter for attachment as sheathing. The 3mm long sheets were formed into cylinders by press-breaking with radius tools forming a smooth cylindrical surface.

After preparation, the test piles were sheathed from 0.6m from the top of each piling to 3m down the piling. Once in place, this allowed 0.6m of sheathing below the mean low tide and 1.2m above the normal high tide.

Seven pilings were sheathed by direct welding of the preformed sheet to the steel piling. Four were cathodically protected below the waterline and three were not.

The sheathing for direct welding was preformed to the 170mm diameter of the steel pipe allowing for about 13mm overlap at the longitudinal seam. These cylinders were then slid into place over the piling, clamped and welded along the overlapped seam with MONEL 187 (nominally 70-30 Cu-Ni) welding electrodes. The sheathing was then welded around the circumference of the pipe at both ends with MONEL190 welding electrode (nominally a 65Ni-Cu) with the intention of sealing the underlying steel from exposure to sea water.

Three more sheathed pilings were prepared to the same procedure but a 14mm diameter hole was punched 80mm from the bottom of the sheathing prior to welding. These holes were to provide sea water access to the back of the sheathing and underlying steel. All three were exposed without cathodic protection.

For the concrete insulated sheathing, seven pilings were sheathed with a 50mm annular gap between the steel and the Cu-Ni which was filled with ASTM Type 2 Portland cement. This is a cement for general use with a moderate sulphate resistance. Four pilings were exposed with cathodic protection and three without. The copper-nickel sheet was preformed into 0.3x3m long cylinders and the vertical seam welded with MONEL 187 welding electrodes. A series of 3 surface weld beads were also laid down around the inside of each end of these cylinders. These inside surface beads provided surface irregularities for better adherence of the otherwise smooth sheathing to the concrete filler.

After welding these cylinders were placed over the steel piling and clamped with plywood forms to secure the annular space and act as a chute for pouring the concrete. A vibrator strapped to the lower end of the piping assured a complete fill with concrete.

Two controls were sheathed with 0.8mm 65%Ni-Cu alloy 400 sheet. This was too thin to be welded to the piling and so was attached by type 316 stainless screws tapped 150mm apart along the vertical seam and around the top and bottom. No attempt was made to seal the sheathing and no insulating barrier was placed between the sheathing and underlying steel.

An additional 14 piles were sheathed using a butyl rubber compound, supplied by 3M Corporation, as an insulated barrier between the Cu-Ni sheathing and the steel piling. These were an extension to the original project as they had been part of another project which had been disbanded. All of these test piles were cathodically protected. One piling was exposed with a single point contact between the Cu-Ni and the steel piping; this was made by bending the sheathing in one area until it contacted the steel. These were deployed in early 1984 and selected pilings were removed after 5 and 10 years.

The anodes used for all the cathodic protection were of Galvalum III aluminium alloy and were cut into 10x10x20cm sections to allow placement of the anodes on either side of the cathodically protected piling to produce a uniform current and distribution pattern.

4.1.3 Removal and Inspection of the Test Pilings

After 2 years, designated pilings were removed, examined and documented. Biofouling levels were calculated, cross sectional thicknesses of the steel were taken at areas of interest. The aluminium anodes were cleaned of fouling and pickled in 30% nitric acid at room temperature and weighed to calculate the mass loss and calculate consumption rates.

Five and ten year removals were examined in a similar manner. In addition, the piles were sectioned transversely to determine corrosion loss as a function of elevation. Thickness measurements were made at 6 locations equi-distant around the steel circumference of each transverse section and subtracted from the original nominal wall thickness.

4.2. Kure Beach

4.2.1 Materials

A second series of experiments were conducted by the LaQue Center in the Atlantic Ocean at Kure Beach, North Carolina, USA, at an oceanfront site*(15)*. A total of six pilings were exposed to oceanfront wave action, three on the north side and three on the south side of a fishing pier, slightly offshore from the wave breaker line. Each side had a steel control piling, a Cu-Ni sheathed piling insulated from the steel with concrete and a steel piling directly welded with Cu-Ni sheathing. The pilings were exposed late 1987. The level of biofouling was documented at intervals and potential measurements taken to determine the level of cathodic protection from the zinc anodes that had been welded to each piling prior to exposure.

In July 1996 the pier was totally destroyed by two hurricanes. All six piles were removed for repair and re-exposed at approximately the same locations on the newly rebuilt pier. After approximately 16 years total exposure, the piles were abandoned in situ and no further reporting is scheduled.

4.2.2 ***Preparation and fabrication***

Six pilings of steel to ASTM A36, each 12.2m x 0.2m, were prepared and end caps welded to them. 90-10Cu-Ni alloy (C70600), 3.2mm thick was preformed into 3.05m long cylinders; the longitudinal overlap was welded with MONEL 187 welding electrode. In each case two cylinders were butt-welded together along the circumference with MONEL 187 welding electrode to make 6.1m long cylinders to be used as sheathing and welded to 2 steel pilings with MONEL 190 welding electrode.

Both the direct welded sheathing and concrete insulated sheathing were applied in a similar manner to those already described in 4.1.2.

The steel inserts of three cast zinc anodes were welded directly to each piling (sheathed and bare) in the area that would become the mid point of the 3-4m full immersion zone.

5.Results

5.1 Wrightsville Beach

For the two year exposures, the extent of biofouling accumulation on the directly welded sheathing was greater than that on the concrete insulated sheathing and comparable to that on the bare steel. However, after 5 and 10 years the biofouling accumulation on the bare steel had dramatically exceeded that on the directly welded sheathing. Table 2 provides a summary of the results of biofouling accumulations on the pilings after 5 and 10 years.

Piling	kg/m^2	Percent coverage	Biofouling Organisms
Bare Steel(unsheathed control)			
5 years 10 years	18.00 12.00	100.0 100.0	massive barnacles, oysters, codium, sea liver, clams, sea urchin, coral, filimentous bryozoans.
Concrete-Insulated Cu-Ni on Steel			
5 years 10 years	0.36 0.14	1.9 1.2	only scattered barnacle shells
Cu-Ni Directly Welded to Steel			
5 years 10 years	7.95 4.43	44.3 36.8	moderate barnacles, oysters, codium sea liver, sponge, filimentous bryozoans, colonial tunicate.
Rubber-Insulated Cu-Ni on Steel			
5 years 10 years(average 3 pilings)	0.26 0.51	1.4 4.2	scattered barnacles, oysters, codium, colonial tunicate, filimentous bryozoans.
Rubber-Insulated Cu-Ni on Steel with Galvanic Couple (single point contact)			
5 years 10 years(average 2 pilings)	4.59 7.7	25.5 42.8	moderate barnacles, oysters, codium, tunicate, colonial tunicate, encrusting and filimentous bryozoans

Table 2. Biofouling Mass on 90-10 Cu-Ni Sheathed Steel Pilings after Five and Ten Years

Organisms observed included barnacles, oysters, codium, tunicate, colonial tunicate, encrusting and filamentious bryozoans but not all were present on all pilings. After five years the mass accumulated on the bare steel piling was more than twice as great as that which accumulated on the directly welded 90-10 Cu-Ni piling and more than 25 times higher than the average amount that attached to the concrete and rubber insulated sheathing. Only a few scattered barnacles were seen on the concrete insulated Cu-Ni sheath after five years. After ten years, the unsheathed bare steel was still heavily fouled but its fouling mass was somewhat reduced. However, the fouling mass of the rubber insulated pilings shows an increase over time while the concrete insulated pilings show a decrease when the five and ten year results are compared. The variability in fouling mass over time are normal, especially when it is appreciated that this is a field test and therefore not conducted under controlled laboratory conditions. Two of the rubber insulated pilings had developed a short between the sheathing and the steel after 10 years which accounted for the corresponding greater extent to fouling on those samples and they have been categorised as forming a galvanic couple in Table 2. It is reasonable to assume that the two hurricanes that affected the area in 1996 reduced the total accumulation of biofouling on heavily fouled pilings. All the insulated sheathed pilings continue to resist fouling after ten years. Any restricted colonisation that did occur on these was easily dislodged by the wiping action associated with the pile removal operation.

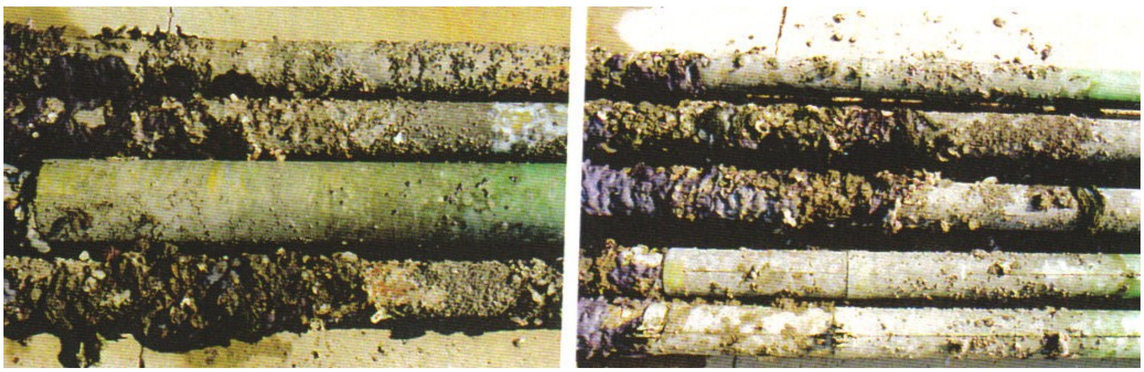


Figure 5. Appearance of biofouling on pilings in the full immersion and tidal zones after 10 years exposure. Left hand side-Top to Bottom: Ni-Cu Alloy 400, Cu-Ni 90-10 sheathing directly welded. 90-10 Cu-Ni sheathing insulated with concrete and steel control. Right hand side-90-10 Cu-Ni piles insulated with butyl rubber; 2nd and 3rd from the top had unintentional contact between the sheathing and steel.

After 15 years, the 4 remaining pilings had to be moved to a nearby location as the dock was damaged by a major hurricane in 1996 and needed repair. The degree of marine fouling at that stage was noted to be unsheathed steel control=mechanically fastened alloy 400>directly welded 90-10 Cu-Ni>concrete insulated 90-10 Cu-Ni.

Corrosion loss measurements of the steel are shown in Figures 6 and 7 for the 5 year removals and Figure 8 for the 10 year removals. Throughout the 10 years there was no measurable thickness loss of either the Cu-Ni sheathing or the steel areas protected by the directly welded sheathing or the insulated sheathing. After two years there was no evidence of accelerated attack due to galvanic corrosion of the steel at the intentional defect (welded sheathing with no cathodic protection). After 5 years there was an indication of slightly greater thickness loss of the steel (1mm).

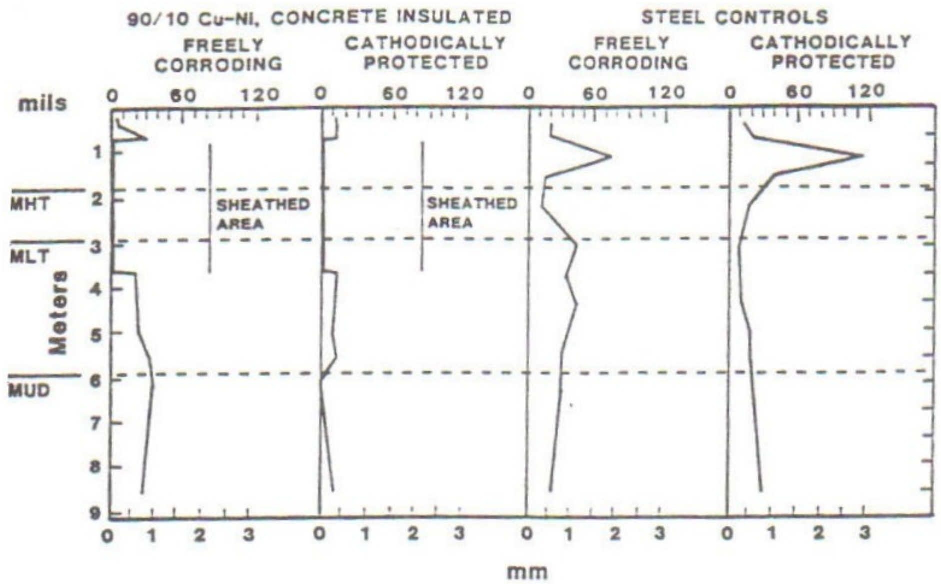


Figure 6. Measured average metal loss for steel piles with concrete-insulated Cu-Ni sheathing and steel controls after 5 years.

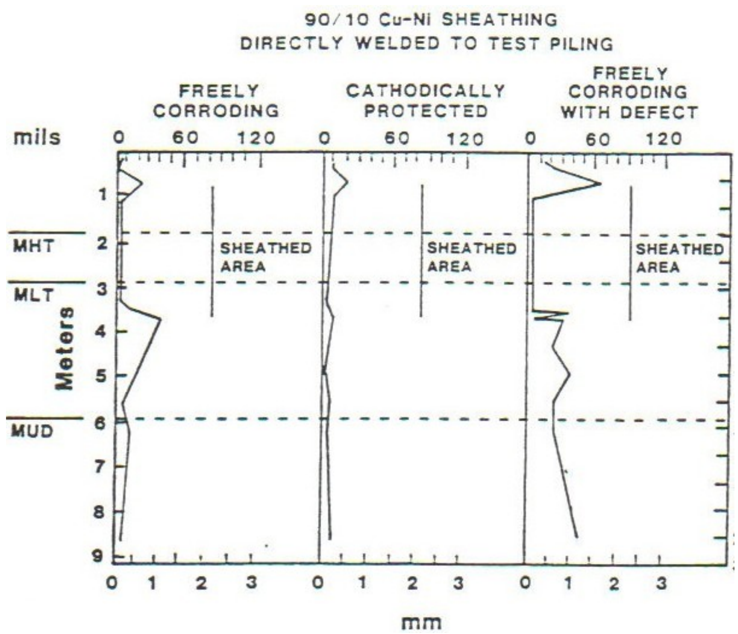


Figure 7. Measured average metal loss for steel piles with directly-welded Cu-Ni sheathing after 5 years

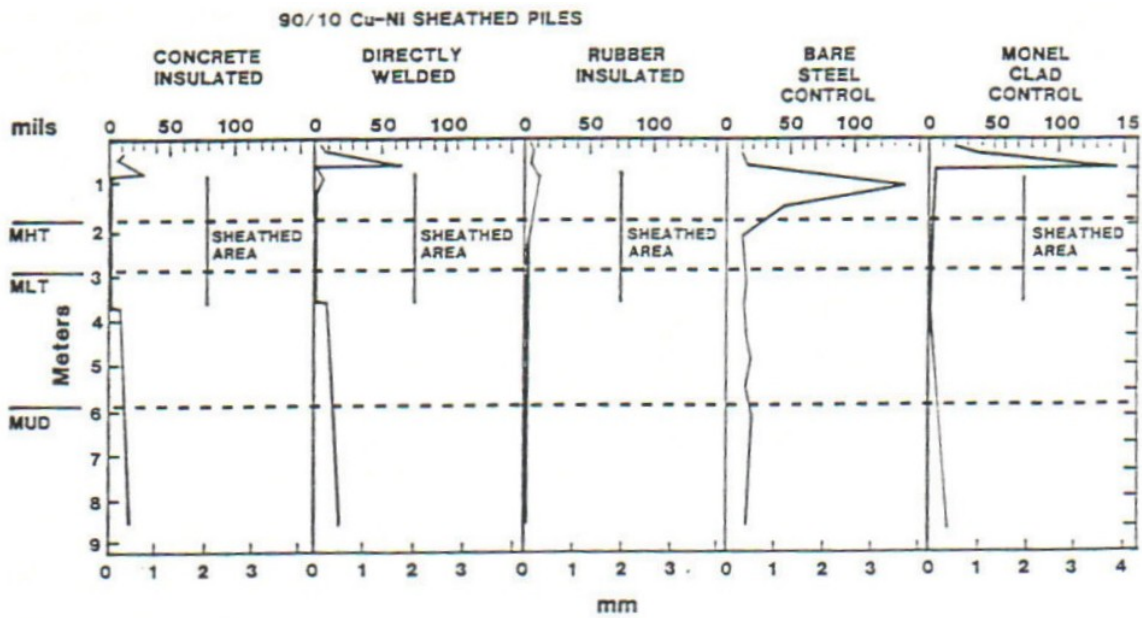


Figure 8. Measured average metal loss for steel pilings sheathed in various ways and steel control, after ten years.

It was also observed that even in the case where the sheathing was directly welded to the steel and exposed without cathodic protection for five years there was no grossly accelerated attack of the steel immediately above or below the sheath. The average corrosion rates in the steel adjacent to the sheathing below the mean low tide point did not exceed 0.25 mm/y, which is no higher than the corrosion rate of the freely corroding, unsheathed steel control pilings. Of course, exposure of any steel piling without cathodic protection is not recommended.

Through wall corrosion had occurred in the steel above the sheathing in the atmospheric zone for the directly welded 90-10 Cu-Ni and 65Ni-Cu alloy 400 pilings after 15 years exposure and was repaired 3 years later. This illustrates the need for protection of steel above the sheathing in practical structures for example with paint or thermal spray coatings.

The galvanic anodes used on the cathodically protected piling were cleaned and weighed; mass loss and consumption rates are given in Table 3.

*. combined weight - two anodes per piling		
Piling Type	**Weight Loss* grams**	**Consumption Rate kg/yr**
Bare Steel Control		
2 years 5 years 10 years	716.4 1880.6 2316.1	0.36 0.38 0.23
Concrete-Insulated Cu-Ni on Steel		
2 years 5 years 10 years	755.3 256.6 181.8	0.38 0.05 0.04
Cu-Ni Directly Welded to Steel		
2 years 5 years 10 years	414.1 687.6 2050.8	0.21 0.14 0.21

Table 3. Galvanum III Anode Weight Loss and Consumption Rate when Coupled to 90-10 Cu-Ni Sheathed Steel Pilings

In the two-year exposures, the directly welded piling displayed a lower anode consumption rate than the bare steel; the concrete insulated consumption rate was comparable to that of the bare steel. After five years of exposure, both the directly welded and the concrete insulated pilings displayed reduced consumption rates. After ten years of exposure, the anode consumption rate of the directly welded Cu-Ni on steel pilings returned to the rate initially observed after two years. This variability can again be expected as these are field exposures and are not conducted in a laboratory under controlled conditions.

5.2 Kure Beach

Inspections over the first 2 years of exposure revealed little change in the appearance of the pilings. During subsequent inspections, the pilings with the concrete insulated sheathing, barnacle attachments covered approximately 30% of the sheathed area in the tidal zone after 3 and 4 years and about 40% after 6 years. In July and September 1996 two hurricanes totally destroyed the pier, the pilings were bent at the mud line due to the intense wave actions during the storms and remained in place until February 1997 when re-building of the pier began. At that stage, biofouling was removed from the sheathed areas and the corresponding areas on the bare steel piles and weighed and is shown in Table 4.

Pilings	kg/m^2
Bare Steel (north side)* Bare Steel (south side)*	3.61 2.92
Directly Welded on Steel (north side) Directed Welded on Steel (south side)	2.34 2.34
Concrete Insulated Steel (north side)** Concrete Insulated Steel (south side)	1.56 0.59

***.** unsheathed - experimental control
****.** partially shorted

Table 4. Biofouling Mass on 90-10 Cu-Ni Sheathed Pilings after 10 Years of Exposure on the Ocean Front at Kure beach, North Carolina, USA

As expected, the bare steel experiment controls had the highest biofouling mass, which was 500% to 600% greater than the value obtained from one of the concrete-insulated pilings (south side). The biofouling mass on the other concrete insulated piling (north side) was two-thirds the average amount accumulated on the directly welded piling. It was noted that the large accumulation on the concrete insulated piling (north side) was attributed to it being partially electrically shorted and therefore is more representative of a directly welded rather than insulated sheathing. The biofouling mass of the directly welded piling was 65% to 80% of the amount which grew on the bare steel experimental control pilings. However, the fouling on the latter Cu-Ni directly welded-to-steel pilings, was poorly adherent and easily removed.

The pilings were repaired and returned to the rebuilt pier. Occasional inspections were carried out and the pilings remain in situ now that the project has ended.

6. Discussion

The Wrightsville Beach Trails aimed to examine the viability of 90-10CuNi for corrosion and biofouling protection in the splash, spray and tidal zones. The test programme compared levels of fouling on electrically insulated vs non insulated Cu-Ni sheathing, anode consumptions with and without sheathing, corrosion rates of steel behind the sheathing and the sheathing itself, galvanic attack at the top and bottom steel/sheathing junctions when welded in position.

Physical measurements of the depth of attack for the two year removals and extensive sectioning and thickness measurements for the 5 and 10 year removals were performed. The results indicated complete protection of the steel behind the sheathing in the splash and spray zones. When a hole was intentionally present in the sheathing to allow water ingress, 5 years had passed before thinning of the steel was detectable (1mm). In practice cathodic protection is routinely applied to steel structures under the water line and this would not have occurred.

There was no measurable loss of thickness of the Cu-Ni sheathing itself in the case of the directly welded and insulated pilings. Post exposure measurements on submerged areas of steel on the cathodically protected sheathed piles showed that corrosion losses were comparable to those at the corresponding areas on the cathodically protected bare steel controls. The mass of biofouling accumulation on the sheathing that was electrically insulated from the steel was 1-4% of that present on the bare steel after 10 years exposure and low levels of fouling continued through 20 years. Pilings with the directly welded sheathing accumulated less than 40% of the biofouling mass compared to the bare steel controls.

The sheathing also reduced the anode consumption rates particularly for 5 and 10 year removals. The most significant reduction was for the insulated sheathing, presumably because the concrete reduced the area of metal requiring cathodic protection. The anode consumption associated with the directly welded sheathing was lower than for the bare steel and the corresponding anode output was lower. This is considered to be due to the favourable polarisation behaviour of the 90-10 Cu-Ni alloy and is in accordance with the early trials described in Section 2. However, the current demand for the directly attached alloy 400 sheathed pile was similar to that for the directly welded 90-10 Cu-Ni and Section 2 indicated Cu-Ni would have been less than alloy 400.

The potentials indicated satisfactory levels of cathodic protection throughout the test.

Corrosion at the sheathing/steel atmospheric junction eventually (15 years) perforated the steel pipe in both the alloy 400 sheathed and direct welded 90-10 Cu-Ni sheathed pilings indicating it is important to maintain coatings at the steel/sheathing interface at the top of the sheathing. Cathodic protection will eliminate any galvanic effects at the bottom interface although the data from these exposure results do not seem to indicate that this is at all pronounced.

The Kure Beach trials were less detailed and have produced more limited results. The biofouling mass measurements were taken after 2 hurricanes had damaged the pilings. However, they have served to reinforce the general trends found in the Wrightsville Beach trials; namely, insulated Cu-Ni sheathing provides the best resistance to biofouling and even directly welded sheathing with cathodic protection on the steel can achieve reduced fouling levels to bare steel pilings.

The Morecambe Field jackets have been inspected at intervals since initiation of service in 1985. Underwater video records of the condition of the steel and sheathed splash zone regions have been taken and show good performance of the Cu-Ni sheathing. There is no significant corrosion of the Cu-Ni sheath or adjacent steel. With the cathodic protection, marine fouling has occurred on the Cu-Ni since it is welded directly to the steel, but comments after 12 years service indicated that this was light compared to the steel below the sheath where heavy mussel fouling and soft hydroid growth ranging from 40 to 90 mm thick is seen. Divers at that time also commented that the fouling is more loosely attached to the Cu-Ni and easy to remove with a hand scraper. Such findings correspond well to the expectations given by the LaQue Center trials.

7. Conclusions

The Wrightsville Beach demonstration programme has shown complete protection of the steel behind the sheathing. The corrosion rate of the Cu-Ni was very low and uniform. Coatings should be applied and maintained on the upper steel/Cu-Ni interface and any steel area above in the atmospheric zone.

Long term data shows that accumulation of biofouling on insulated Cu-Ni was 1-4% of the bare steel controls. In the case of directly welded sheathing, there were over 50 and 60% reduction in the biofouling mass after 5 and 10 years exposure respectively representing a significant reduction in structure weight and wave loading.

The exposure trials and service performance of sheathing in the Morecambe Field clearly show that sheathing steel marine structures with Cu-Ni can provide long-term maintenance free protection in the splash, spray and tidal zones on marine structures where corrosion can otherwise be very severe. For the greatest resistance to macrofouling, the sheathing needs to be electrically insulated from the steel structure.

8. References

1. E.V. Creamer.Splash Zone Protection of Marine Structures. Offshore Technology Conference, Paper No. 1274, Houston,Texas, 1970
2. D.J. Hopkins, MONEL Alloy 400 Sheathing for Complete Splash Zone Protection. Offshore Europe 77, Aberdeen, September 1977.
3. R.W. Ross, Jr and D.B. Anderson. Protection of Steel Piling in Marine Splash and Spray Zones-The Metallic Sheathing Concept. Proceedings of the 4th International Congress on Marine Corrosion and Fouling. Antibes, France June 1976.pp461-473
4. W. Kirk. Metallic Sheathing for Protection of Steel in Seawater. Materials Performance.26 9 pp23-28. 1987
5. H.Arup. Cathodic Current Demand of Copper Nickel Sheathed Piling. Danish Corrosion Centre. INCRA project 371.
6. J.A.Ellor and G.A.Gehring Jr. Galvanic Corrosion of Copper Nickel Sheathed Steel Piling. Ocean City Research Corp. INCRA project 368. March 1987
7. S.Husa. Stray Current Corrosion. Marintec. INCRA Project 372. September 1986
8. D.T.Peters, H.T.Michels, C.A.Powell. Metallic Coatings for Corrosion Control of Marine Structures. International Workshop on Control fro Marine Structures and Pipelines. Galveston,Texas. February 1999.
9. C.A.Powell and H.T. Michels. Copper-Nickel Alloys for Sea Water Corrosion Resistance and Antifouling-A State of the Art Review. Corrosion 2000.NACE March 2000.
10. S. Campbell. R.Fletcher and C.Powell. Long Term Exposure trials Evaluating the Biofouling Resistance of Copper Nickel Alloy Sheathing Materials. The 12th International Congress on Marine Corrosion and Fouling. July 2004
11. Preventing Biofouling with Copper-Nickel. CDA, UK Publication 157

12. L.Boulton and C.Powell. Controlling Biofouling on Ferry Hulls with Copper Nickel. 10th International Congress on Marine Corrosion and Fouling. February 1999. Melbourne
13. R.Curruthers. The Use of 90/10 Cu-Ni Alloy as a Splash Zone Cladding. Paper 6 proceedings of CDA Conference on Copper Alloys in Marine Environments. Birmingham.UK. April 1985
14. F.W.Hammond. Twenty year results of Long Term Copper Nickel Sheathed Piling Studies. Final Report ICA project 358. June 2005
15. F.W.Hammond. Splash Zone Corrosion of C70600 After 16 years Exposure in an Ocean Front Environment. Final Report. ICA project 399. June 2005