Use of Copper-Nickel Cladding on Ship and Boat Hulls

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Contents

Topics Covered 2
Introduction 2
Practical Experience and Economic Aspects 2
Fire boats with Cu/Ni-clad hulls 4
Fouling resistance and corrosion protection 6
Forming and welding 9
Observation and reflections on the service behaviour 10
Summary 12
References 13

Topics Covered

- Practical experience and economic aspects of the use of CuNi10Fe1Mn clad plate for the hull of boats and ships.
- Recent applications in fire boats.
- Forming and welding.
- Precautions taken to enhance the resistance to fouling and corrosion protection.
- Measurements made to determine the free corrosion potential.
- Phenomena observed in service.

Introduction

90/10 copper-nickel, equivalent to CuNi10Fe1Mn (as per DIN 17670) or CN 102 (as per BS 2870), occupies a special place among the range of copper-base alloys containing nickel. Apart from displaying high resistance to uniform and local corrosion when subjected to seawater, this material also presents comparably good resistance to erosion. A third advantage is this alloy's extraordinary resistance to fouling in seawater [1]. Familiar fields of application in which CuNi10Fe1Mn has been successfully used for many years include seawater-carrying apparatus and pipelines. Where, in addition to highly corrosive conditions, a great deal of mechanical stress has to be withstood, as for example in intake tubes of seawater desalination plants, steels clad with CuNi10Fe1Mn can be used as economical constructional materials [2].

Because of their corrosion, erosion and antifouling properties, CuNi10Fe1Mn and the steels clad with it are consequently also used as materials in ship and boat hulls. This subject is dealt with in the following, with a summary first of all being given of the knowledge gained so far. This article concentrates on the experience gained during the planning and construction of fire boats ordered from the shipyard of Ortona Navi S.p.A by the Italian Ministry of the Interior.

Practical Experience and Economic Aspects

Two recently published articles [3,4] deal in very great detail with examples where CuNi10Fe1Mn, either solid or in the form of a plate cladding, was used as a constructional material for ship and boat hulls. Tables 1a and 1b have been essentially derived from these two articles. Both tables are concluded with examples of this material's use in Italy in 1984. Table 1a lists examples where the part of the hull in contact with seawater is made entirely of CuNi10Fe1Mn. Table 1b provides an overview of the instances where CuNi10Fe1Mn was put to the test in parts of various large ships.

The published data [3-8] all attest unanimously that, presupposing expert and proper design and processing techniques, the corrosion and fouling resistance expected of CuNi10FelMn by modern day standards is attained. The main precondition for ensuring fouling resistance is that the free corrosion potential of CuNi10Fe1Mn in seawater ($U = \pm 20$ mV_H, i.e. related to the standard hydrogen electrode) does not change towards more negative values.

Due to the fact that marine heat exchanger tubes made of CuNi10Fe1Mn are in general only used where flow rates of up to 3.5 m/s are involved, there were at first misgivings that ships travelling at high service speeds might suffer inadmissibly high material losses due to erosion and corrosion. These misgivings were allayed by measuring the thickness in various practical applications [3,5,7,9]. The maximum thickness decrease was found to have occurred on the sheathed rudder of the Great Land (full power speed 24 knots) where at one location, after 14 months of being additionally subjected to propeller turbulence, a material loss of 0.08 mm was measured. On average, a loss rate of 0.05 mm per year should be reasonable for use in calculations [8].

A further result of the examinations performed on the sister ships Great Land and Westward Venture of the Sun Ship company was the finding that, at 20 µm, the surface roughness of the CuNi10Fe1Mn parts of the ship was considerably less than the 210 µm of the comparably stressed, conventionally painted steel hull. A reduced surface roughness of the ship's hull can be directly related to a decrease in the power requirement, and thus to a reduction in fuel consumption. When studying the cost-efficiency of using CuNi10Fe1Mn instead of conventional materials, the aforementioned aspect gains increasingly in importance in view of rising fuel costs, in particular where large vessels are concerned. Other arguments in favour of the use of CuNi10Fe1Mn, or of steels clad with it, can be found in the reduced volume of maintenance work and downtime. According to a recently published study [9], Cu/Ni-clad steels undoubtedly offer economic advantages for ships with a relative speed of $V\sqrt{L} >= 1.5$ (V = the mean speed in knots under load, and L = the ship length in metres).

Table 1a - Vessels constructed with cupro-nickel hulls

Vessel	**Length m**	**Launched**	**Built**	**Hull thickness mm**	**Operating**
Asperida II	16	1968	Netherlands	4	USA
llona	16	1968	Netherlands	4	Curaçao
Copper Mariner	22	1971	Mexico	6	Nicaragua
Pink Lotus/ Pink Jasmine/ Pink Rose/ Pink Orchid	17	1975	Mexico	4	Sri Lanka
Copper Mariner II	25	1977	Mexico	6 + 2*	Nicaragua
Sieglinde Marie	21	1978	UK	6	UK/Caribbean
Pretty Penny	10	1979	UK	3	UK
(Motobarcapompa VF 541) Sabatino Bocchetto	21.5	1984	Italy	6 + 2*	Italy

* Copper-nickel clad steel plate

Table 1b - Recent applications of cupro-nickel in shipbuilding

Following are the BS equivalents given for the DIN and UNS designations:

UNS	**DIN**	**BS**
C 70400 (ex CA-704)	CuNi5Fe*	CN 101
C 70600 (ex CA-706)	CuNi10Fe1Mn	CN 102
C 72200 (ex CA-722)	CuNi20Fe*	CN 104

* Deleted in DIN 17664, December 1983

Vessel	Particulars
Great Land/Westward Venture	Cu/Ni sheathed rudder on 24 knot RO/RO ship (240 m long) installed in 1975. Additional experiments included test panels mounted on the hull (CA704,- 706, -722).
Container Ship	Rudder and rudder horn, installed in 1981 and 1982, 26 knots, 200 m long, 30000 DWT, CA 706 clad steel and CA706 sheathing.
Oil Tanker (ARCO TEXAS)	4 groups of test panels, CA 706 (3050 mm x 910 mm x 3.2 mm per panel), installed in 1981, 91000 DWT, 15.5 knots.
Emilia Ferry	Two CA 706 clad plates (2000 mm x 6000 mm x 11 + 3 mm) welded on the hull of the ferry boat (136 m long, 9485 DWT, 20 knots), by TIRRENIA Navigazione, Napoli, in January 1984.

Fire boats with Cu/Ni-clad hulls

At the beginning of 1983, Italy's Ministry of the Interior awarded the shipyard of Ortona Navi S.p.A an order to build a first lot of 3 fire boats. At the same time it was decided to use Cu/Ni-clad steel for the submerged part of the hull. The reason for this decision was that the boats were expected to have a greater speed and better nautical efficiency by not being susceptible to fouling. Also, because of the material's high resistance to corrosion, low maintenance costs and high availability were expected.

The diagrams in Figure 1 illustrate the design characteristics of the fire boats. The hull has a length of 22.56 m and is 5.78 m wide. The maximum draught is 2.45 m measured at the rudder, and the displacement is 72 tons. Two marine diesel engines together produce an output of 840 HP which can be turned into a maximum speed of 13.2 knots via two rudder propellers which are rotatable by 360°. The water cannons can be fed with 16,000 litres of seawater per minute which is sucked in via two intakes in the hull.

The submerged parts of the hull are built of steel clad with CuNi10Fe1Mn. Clad steels are composite materials, the components of which - in this case CuNi10Fe1Mn and RINA grade D shipbuilding steel - are joined together in such a way that they do not become detached from one another, either during processing, or later when in service. The plates in question here, measuring 6,000 mm x 3,000 mm x 6 + 2 mm, were roll-clad, and the bond between the base and cladding materials was strengthened by an intermediate nickel layer some 40 μm in thickness.

The chemical composition and the mechanical properties of the material are shown in Table 2. The intensive bond between the clad plate components became apparent during shear tests and was demonstrated by bending tests using a mandrel 1.5 times the plate thickness.

Tensile tests were performed both on the base material and on the full thickness of the clad steel plate (base + cladding metal). Since CuNi10Fe1Mn is lower in strength than steel, the tensile properties obtained during the latter test were somewhat lower, as could be expected.

As a rule, the load-bearing thickness of clad materials is that of the base material, taking into account the requirements of the base material specification. Just how far this thickness could be reduced by including the cladding material, can be inferred from the following equation derived from the standards given in the literature reference list [10,11].

$$\Delta t = \frac{R_c t_c}{R_B t_B} 100\ (\%)$$

Where Δt is the proportional reduction of the base material thickness, R the yield or tensile strength on which the calculation is based, and t the thickness of base material B and/or of cladding material C.

Figure 1 – Design characteristics of fire boats built by the shipyard of Ortona Navi SpA

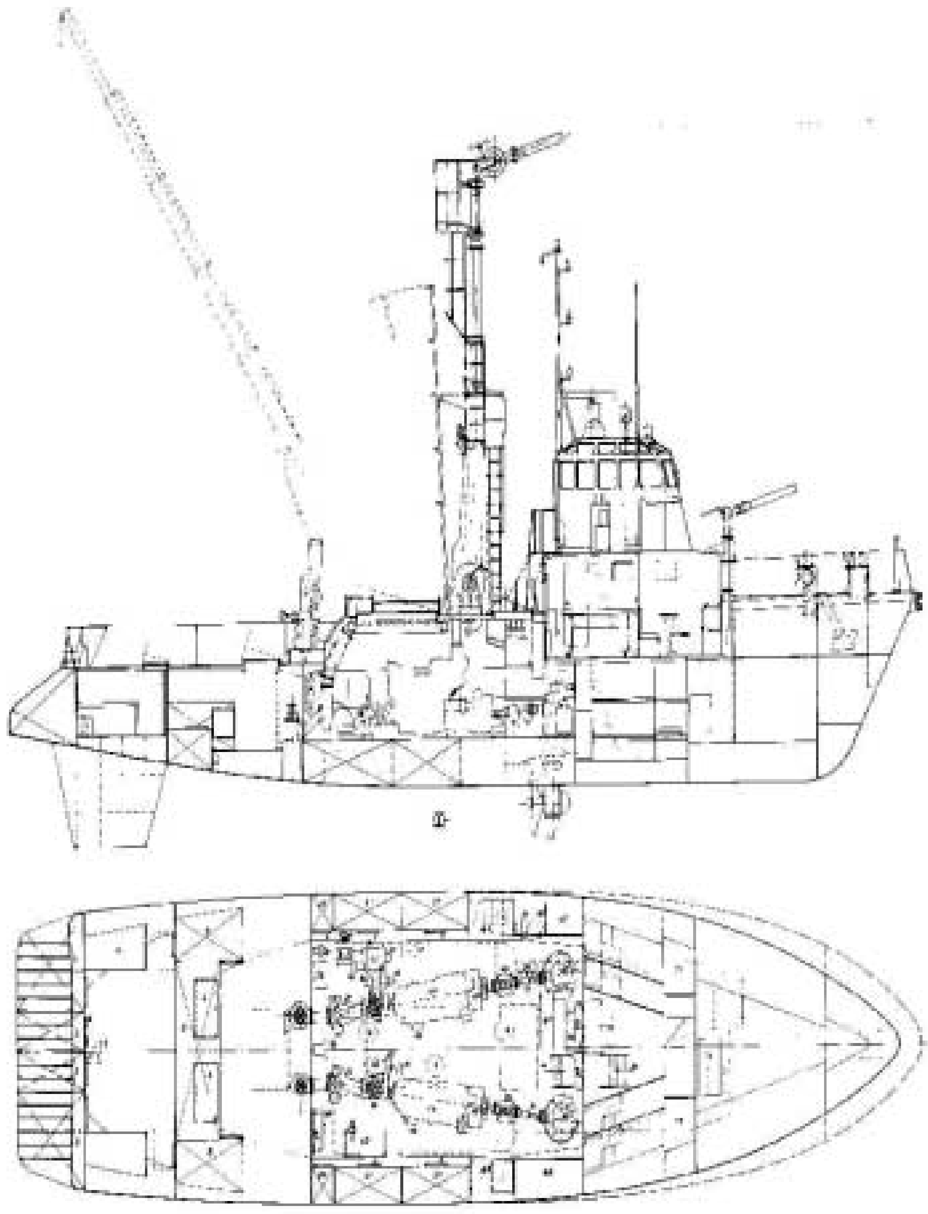


Table 2: Clad steel plates in fire boats: chemical composition and mechanical properties

Material	**Chemical composition**										
	% C	**% Si**	**% Mn**	**% P**	**% S**	**% Al**	**% Cu**	**% Ni**	**% Zn**	**%Pb**	**% Fe**
RINA Grade D	0.09	0.27	1.08	0.020	0.011	0.031					Rest bal.
CuNi10Fe1Mn	0.004		0.81		0.02		87.14	10.4	0.01	0.005	1.57

Material	**Plate thickness mm**	**Yield strength R_e N/mm^2**	**Tensile strength R_m N/mm^2**	**Elongation A_5%**	**Shear strengths N/mm^2**
RINA Grade D		≥233	400 - 490	≥22	≥140
CuNi10Fe1Mn	Requirements	≥100	≥300	≥30	
Base metal	6	264 - 299	420 - 446	29 - 36	
Clad plate	6 + 2	258 - 276	410 - 425	33 - 42	195 - 207

Fouling resistance and corrosion protection

Early during the planning of the fire boats, intensive thought was given to the method of ensuring corrosion protection and fouling resistance. The main risks to be borne in mind, and some of the problem solutions, could be derived from articles already written about the experience gained in this field [5,6]. Various laboratory experiments were also performed to supplement our own range of experience.

The mechanism responsible for the fouling resistance of CuNi10Fe1Mn has not been fully investigated. It is, however, assumed that a more or less continuous surface reaction involving the formation of copper ions forms the basis of this mechanism [12,13]. From experience it is known that such reaction conditions are fulfilled whenever there is a free corrosion potential in oxygenated seawater. The electrochemical reactions of the process include, on the one hand, the reduction of oxygen on the cathode ($O_2 + 2H_2O + 4e^- \leftrightarrow 4OH^-$) and, on the other hand, oxidation of copper on the anode ($Cu \leftrightarrow 2e^- + Cu2^+$). Both a decrease of the cathodic partial current, for example caused by a lack of oxygen in the seawater, and a hindrance of the anode reaction due to the corrosion potential shifting to more negative values, can affect the fouling resistance.

It has been found that the greatest danger posed to the fouling resistance is a galvanic coupling of the CuNi10Fe1Mn with a less noble metal, thereby causing a change in the corrosion potential. Figure 2 illustrates this change in potential on a CuNi10Fe1Mn test piece short-circuited with EH 36 grade shipbuilding steel and with zinc in artificial, oxygenated seawater. After interrupting the short circuit the free corrosion potential typical of CuNi10FelMn gradually reappears, as the diagram in Figure 3 shows.

Figure 2 - Corrosion potential of CuNi10Fe1Mn coupled with shipbuilding steel and with zinc

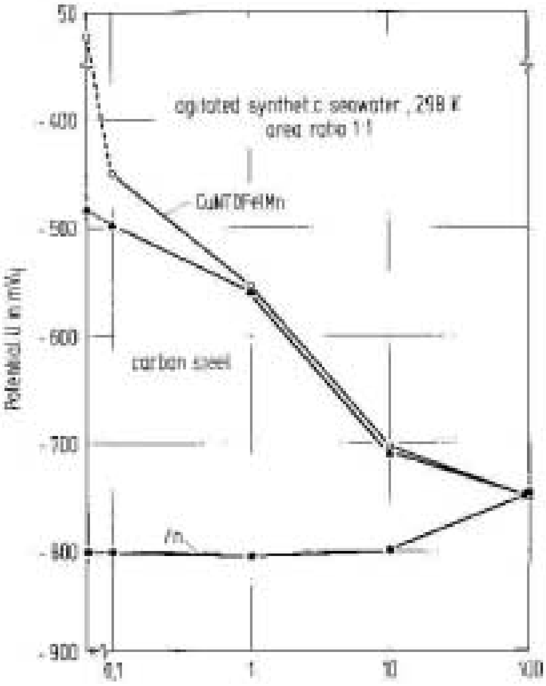
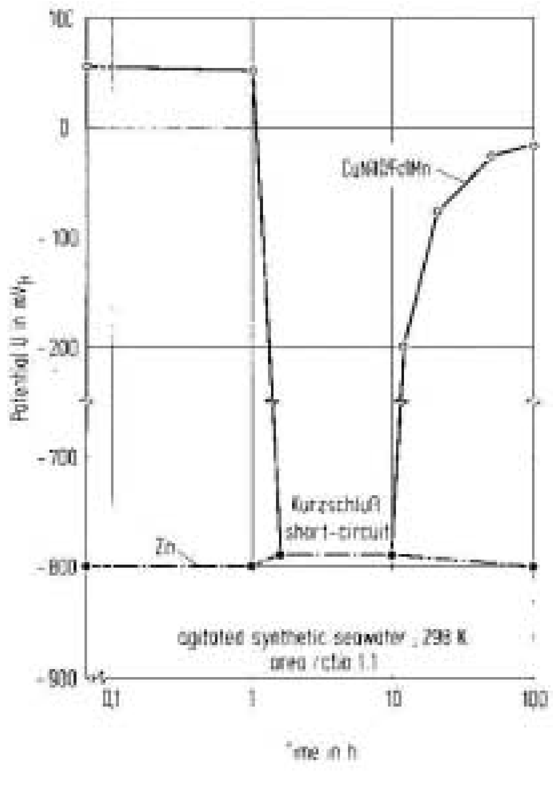
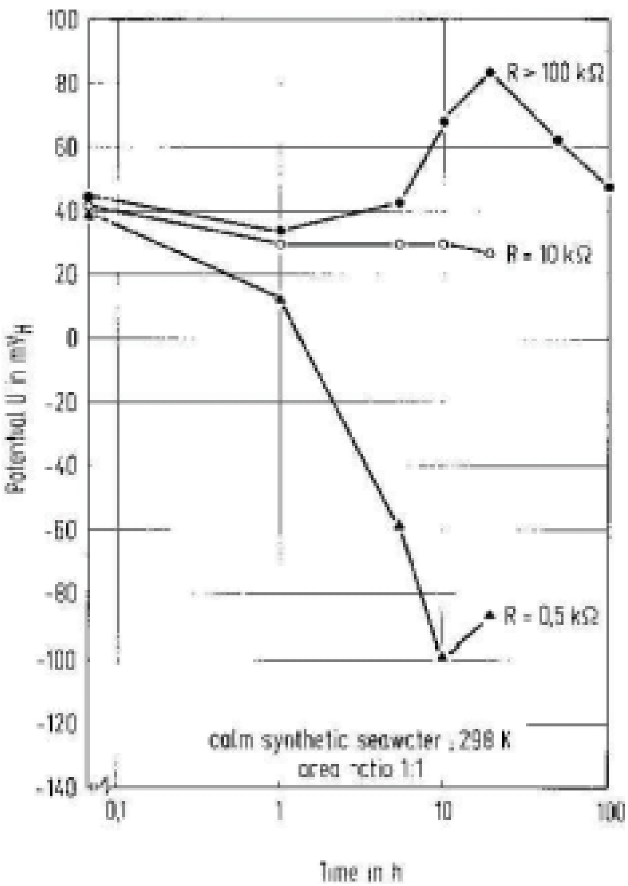


Figure 3 – Corrosion potential of CuNi10Fe1Mn temporarily coupled with a zinc anode



Test results in answer to the question of how great the electrical resistance between the CuNi10Fe1Mn and another metallic material should be, are shown in Figure 4. In these experiments the copper-nickel was coupled with shipbuilding steel in series with different electrical resistances. According to the test results, resistances greater than 0.1 MΩ appear to prevent an unwanted interaction between various types of metallic materials. The characteristic potential peak observed on highly insulated samples is caused by a surface deposit on the copper-nickel in the calm, i.e. non-stirred electrolyte used here. This was constantly borne in mind during the design and construction of the boats. For example, the rudder propellers were installed in the ship's hull in such a way that, in a dry state, there was a transition resistance of more than 300 MΩ between the propeller housing and the vessel's skin.

Figure 4 - Corrosion potential of CuNi10Fe1Mn coupled with shipbuilding steel in series with various resistances



Of course, also where these boats were concerned, it had to be ensured that not only the hull, but also the remaining parts coming into contact with seawater had adequate corrosion protection. This requirement could be met in some cases by using materials which, as was known from experience, are resistant to seawater. For example, the submerged portion of the rudder propellers (Figure 5) consists partly of aluminium-bronze G-CuAl10Ni (as per DIN 1714) or AB 2 (as per BS 1400), and partly of austenitic cast iron GGG NiCr 20 2 (as per DIN 1694) or AUS 202/B (as per BS 3468). The components made of the latter-mentioned material were given a conventional coal tar epoxy base coating.

The seawater-carrying tubes in the boat are of conventional marine engineering design. Like the boat's hull, the seawater intakes for the cooling water, and for supplying the water cannons, are made predominantly of Cu/Ni-clad plate. They are closed off by aluminium bronze slide-gate valves G-CuAl10Ni (as per DIN 1714) or AB 2 (as per BS 1400). An electron-conductive connection between the successive metal parts of the construction was avoided by appropriately insulating the flanged joints on the intake and outlet sides of the slide-gate valves.

Figure 5 - Rudder propeller and water intakes

Forming and welding

Figure 6 shows the bow of one of the fire boats during the construction phase. The shape of the clad hull section, indicated by individual plates, was obtained by cold bending under shipyard conditions.

Figure 6 - Bow area in the process of being welded

Figure 7 - View of a fire boat hull built of Cu/Ni-clad steel

In spite of the partly very small radii, no loosening or detachment of the clad material was observed.

The clad steel plates were welded in accordance with the rules of engineering drawn up for this group of materials. Tacking and welding of the weld root was first of all carried out on the base material, i.e. from the steel side. The welding filler metals had been selected to match the shipbuilding steel used. After the root had been ground and the weld groove cleaned, shielded metal arc welding was continued from the clad side. As had been the case in preliminary trials, the first filler layer on the steel consisted of a nickel-base alloy, NiCu30Fe. This was followed by cover layers using a CuNi30Fe electrode.

It can be seen from Figures 6 and 7 that the welding of the boat's hull also had to be performed in non-down-hand position. In doing so, particular attention had to be paid that as little iron as possible from the base material was diluted with the cladding materials so as not to adversely affect the corrosion behaviour in the weld region. Integral iron contents of between 3 and 5% in the CuNi30Fe weld metal were assessed to be largely uncritical [7,4].

Figure 8 shows a further design detail. One side of the stabilizing rudder was sheathed in CuNi10Fe1Mn sheet (3 mm). The joining technique was similar to that used to weld the clad material.

Before commissioning of the vessel, all of the welds were ground to give the boat's hull an optimally low friction resistance. Figure 9 shows the first of the fire boats, VF 541 "Sabatino Bocchetto", shortly after its launch at the beginning of November 1984. It can be seen that the topsides are conventionally coated. The coating slightly overlaps the clad zone, the latter extending some 100 mm above the waterline.

Figure 8 - Boat stabilizing rudder sheathed on one side with 3 mm CuNi10Fe1Mn-sheet

Figure 9 - Fire boat VF 541 "Sabatino Bocchetto" launched in November 1984

Observation and reflections on the service behaviour

After the launch, the corrosion potential was measured at various points of the clad hull, partly by employing a diver. Use was made of a mobile Ag/AgCI/KCl_{sat}-type reference electrode. The values obtained were always around $U = 20\ mV_H$ and therefore, regarding fouling resistance requirements, within the potential range expected for the free corrosion of CuNi10Fe1Mn in seawater.

In spite of the care taken, swarf from grinding the shipbuilding steel had become deposited by accident at one location of the copper-nickel surface. This location very quickly became evident in the form of "rust", so that cleaning could then be carried out accordingly. This observation seems to be worth mentioning in connection with the frequently asked question of how a Cu/Ni-clad ship's hull behaves when its cladding becomes damaged. If the Cu/Ni were perforated in the process of being damaged, the location in question would become apparent relatively quickly because of the development of ironbearing corrosion products. Of course, the corrosion potential of the Cu/Ni, too, would simultaneously be found to have shifted in the cathodic direction. Theoretically the corrosion rate of the exposed steel can become unusually high if, in the process, attention is only paid to the potential's shift in the anodic direction and to the unfavourably high surface ratio between the Cu/Ni cathode and steel anode. Under unfavourable test conditions in laboratory experiments lasting a year steel plate thickness losses of up to 6 mm were measured [5].

Where the type of ship under discussion here is concerned, it can be assumed that the danger of damage is, *a priori*, very slight. When mooring, fire boats touch other vessels or objects only above the seawater level. The boats also have a relatively small draught. A further safety factor is that due to the metallurgical bonding the clad steel plate can be expected to behave as an entity under heavy deformation, and even when subjected to serious gouging action the Cu/Ni surface can be expected to remain effective. Considerable mechanical stress is therefore required to damage the clad material to the extent that the copper-nickel is completely removed and the steel exposed. In such a case the ship would need repairs, regardless of whether material clad with Cu/Ni has been used or not.

After some 2.5 months in the Adriatic the first fire boat was put into dry dock again to undergo additional installation work. This provided the opportunity of inspecting all the parts of the ship constructed of Cu/Ni-clad material. With satisfaction it was found that the CuNi10Fe1Mn was totally devoid of fouling, as is shown in Figure 10. The CuNi30Fe-welds had a perceptibly darker colour. The welding zones of the sheathing on the rudder displayed the first signs of fouling, but this could be removed by light rubbing. The fouling on the coal tar epoxy coated parts of the rudder propellers, in contrast, proved to be more adherent (Figure 11). All of the additionally installed components, including the water intakes, were in perfect condition and without any signs of corrosion.

Figures 10a and b - Bow area in Cu/Ni clad steel before launching (a) and after 2.5 months in service in the Adriatic (b)

Figure 11 - Hard shell fouling on the coal tar epoxy coated propeller shaft tunnel after 2.5 months in service

Summary

When exposed to seawater, CuNi10Fe1Mn clad plate provides great resistance to wear and local corrosion as well as a relatively good resistance to erosion and extraordinary resistance to fouling. It is because of these advantages that CuNi10Fe1Mn and the corresponding clad plate have been used successfully for a long time in equipment and pipelines exposed to seawater.

This paper uses fire boats as an example to illustrate that Cu/Ni clad plate can be an interesting material in shipbuilding. Apart from corrosion-specific aspects, there are economic reasons for the use of CuNi10 Fe1Mn and corresponding clad plate. The amount of hull maintenance diminishes because of the absence of fouling on CuNi10Fe1Mn plate. Downtimes occur less frequently, resulting in a decrease in maintenance and an increase in availability.

The examples of application shown permit the conclusion that with adequate construction and processing the resistance to corrosion and fouling to be expected of the latest state of art in the use of CuNi10Fe1Mn can be achieved with clad plate without any exception.

The mechanism bringing about the CuNi10Fe1Mn resistance to fouling is not quite clear yet. Experience has shown that the biggest danger is an electrical-ohmic connection between the CuNi10Fe1Mn and a lower-grade metal and the resultant change in potential. A transition resistance of more than 0.1 M seems to be sufficient to prevent the undesirable polarization effect. For the design and construction of the boats, these aspects were duly taken into account when choosing the materials and processing the same.

Forming of clad plate is done by way of cold bending under the conditions prevailing at the shipyard. In spite of the local very small bending radii, no disbonding of the clad plate nor separations were noted.

The clad plates were welded along the lines of welding methods adopted for this group of material. The welding filler metals were made to match the materials used. For the intermediate pass, use was made of the NiCu30Fe alloy. For the top welding pass, CuNi30Fe filler metals were used. Prior to commissioning the boats, the welds were ground to reduce to a minimum the frictional resistance of the hull.

Early in 1984, after launching the first boat, corrosion potential measurements were performed at various spots of the clad hull. The figures measured were within the range of potential to be expected for free corrosion of CuNi10Fe1Mn in seawater.

After 2.5 months of service in the Adriatic Sea the fire boat was taken into the dry dock for inspection. The CuNi10Fe1Mn-hull was completely exempt from any fouling. The CuNi30Fe welds presented a definitely darker colour.

Judging by the results obtained so far, the objective of improved nautical efficiency of the boats plus less maintenance and greater availability has been reached.

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