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DEVELOPMENT WITH AND CORROSION PERFORMANCE OF COPPER NICKEL CHROME CASTINGS

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Development With and Corrosion Performance of Copper Nickel Chrome Castings

by

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Abstract

Nickel Aluminium Bronze NAB has been used over the past thirty years as the material of some naval sea water systems. During that time there has been significant problems relating to selective phase corrosion. This has been particularly true with respect to weld heat affected zones, associated with welding, necessitated by the need to repair casting defects. To overcome these difficulties the use of CuNiCr alloys have been suggested. This route has been pursued in the UK and this paper reports the current position with respect to casting supply. It also records some recent corrosion results which have still to be explained.

Introduction

In some early post second world war vessels the sea water systems were fabricated from gunmetal. This material suffered from corrosion problems and was not really adequate with respect to the 0.2% proof stress requirement. Consequently the various items tended to be heavy and thus the shock resistance was questionable especially the inherent toughness, which was less than ideal. In the 1960's nickel aluminium bronze, which was higher strength and considerably tougher, was introduced into service in order to counteract these problems. Typical composition for currently used NAB is shown in Table 1.

Nickel Aluminium Bronze material although it exhibited a superior 0.2% proof stress and considerably improved toughness to gunmetal was subject to a corrosion problem which came to be described as "selective phase corrosion." (1). The phenomena was encountered in the casting matrix, when it was subjected to prolonged exposure to sea water, but was more severe in the heat affected zones of welds. As the integrity of castings is always suspect, do to porosity resulting from feeding problems, it becomes necessary to weld repair cast items, to a greater or lesser degree, depending on the size and complexity of the product.

In an attempt to ameliorate the selective phase corrosion problem, a heat treatment was developed which greatly improved the corrosion behaviour of weld heat affected zones and was reportedly beneficial for the equivalent matrix corrosion. This procedure, together with the associated restriction for welding on the wetted surface, has

enabled the sea water systems to be effectively managed in recent years. However management of the system is tiresome, labour intensive and one is never sure if the described procedure will work in all circumstances. In addition, some weld repaired castings are too large to be effectively heat treated and thus circumstances exist where severe corrosion can be expected to occur. More recently the use of low heat input weld deposits have suggested that selective phase corrosion can be reduced in comparison to high heat input deposits. The beneficial effect has been ascribed to the increased cooling rate in the HAZ and the associated suppression of the development of the corrosive K phase. However in order to ensure this effect is maximised there must be close control of the welding operation which is very costly and consequently not generally readily applied.

In the most recent past NDE procedures have been developed which will effectively map the area of selective phase corrosion. The principle drawback of the procedure is that the position of the selective phase corrosion must be identified before mapping can take place. As a consequence it has not been possible to develop a surveying technique which will allow items which have been in service to be inspected in situ, and the sea water systems must therefore still be dismantled for revalidation.

With the objective of solving all the aforementioned difficulties and thereby reducing the overall maintenance costs of some naval sea water systems, a high strength copper nickel chrome, CuNiCr, alloy, was proposed to replace the nickel aluminium bronze alloy. This alloy obtained its strength using the chromium addition. The 0.2% proof strength of the alloy, 300MPa, is greater than the 250MPa 0.2% proof strength of NAB and the alloy is also four times as tough.

CuNiCr Alloy Castings

The CuNiCr alloy composition developed for use in Naval sea water systems is given in Table 1. Over the past decade considerable work has been carried out on the castability and weldability of the alloy (2). In addition the necessary NDE procedures have also been developed where gaps in inspection procedures had been identified.

Over the past 12 months the UK copper base foundry industry has been tasked to produce a number of items from the Naval sea water systems in CuNiCr. The items included a small valve body weighing a few pounds through a larger flanged T-piece of some 100-200 pounds in weight to a 1-1.5 ton return end heat exchanger header. These CuNiCr cast items which meet the specified compositional, strength and casting integrity requirements, have now been delivered by two foundries.

The first castings made in the CuNiCr alloy had two drawbacks, the existence of what was described as linear defects and the occurrence of cracking in weld heat affected zones. These cracks associated with the weld fusion line and HAZ were attributed to the impurities in the alloy and the ductility dip associated with CuNi alloys at a temperature of around 600°C.

The linear defects were large entrapped oxides formed as a result of inadequate turbulence during casting. These oxide skins often formed when two independent molten streams interacted without fusion and were originally the surface oxide formed on cool abutting streams, the lack of turbulence and low temperature being insufficient to break up the surface oxide on the streams at the time of interaction. The oxide films were originally very difficult to identify but with the development of a number of eddy current

techniques it is now possible to reliably identify such defects down to a depth of 10mm. All the castings delivered were examined and shown to be free from the so called linear defects. It should be noted that these defects also occur in nickel aluminium bronze but they are not regarded as a problem and not inspected for.

The weldability of the CuNiCr alloy was originally thought to be questionable due to the observed impurity levels. Recently alloys with relatively high impurity levels compared with the alloy which was eventually found to be weldable have also been successfully welded. This was the result of modifications to the welding procedure. The actual modification involved amending the weld preparation to give a shallower angle. In addition a procedure has been used which effectively butters the preparation with fine low heat input weld beads before depositing the fill passes at a much higher heat input. Using the procedure modification singularly or in combination has developed confidence that material manufactured to the current CuNiCr specification can be welded. The new weld procedures have enabled the original severe control of impurities to be relaxed without detrimentally affecting the material weldability.

Corrosion Behaviour

A demonstration of the corrosion behaviour of CuNiCr material is probably the most important aspect of the acceptability of the alloy as a replacement for nickel aluminium bronze. Its general corrosion susceptibility should be as good as NAB and it must not suffer from corrosion by any alloy specific mechanism. In addition welding should not increase its corrosion susceptibility in the HAZ to any significant degree.

Confidence in the corrosion behaviour of CuNiCr has been gained recently from the examination of two CuNiCr valve bodies removed from a sea water system after 10 years service. The valve bodies show minimal uniform corrosion in the bores and no evidence of crevice corrosion on the flanges. This includes both a flat faced flange and a flange providing sealing via an O ring groove. Although not considered at the time, it would probably have been possible to reuse the valve bodies using replacements for the internal mechanism. Most importantly there was no evidence of selective phase corrosion as would be expected from the use of this alloy. The items are now used to improve confidence in the alloy by illustrating the superb corrosion performance of the alloy.

In order to confirm the general corrosion behaviour of CuNiCr and to develop confidence in the use of welded items made from the alloy a welded silencer tube was tested in sea water flowing at 1.5m/sec. The welded test item/silencer is shown schematically in Figure 1. The four welds in the test section include two circumferential GMA and one EB weld and one EB weld joining the flange to the tube section. The EB welds are autogenous and the GMA welds were made using a GMA consumable with the composition shown in Table 1. The consumable contains a lower level of iron than the main component. It is usually accepted that CuNi alloys used in flowing sea water systems should contain some 0.7 % Fe in order to prevent impingement attack.

The test section was subjected to laminar flow for 10,000hrs and turbulent flow for 5,000hrs at a flow rate of 1.5m/sec. When the test section was finally removed from the flow rig after 15,000hrs it was found that there was minimal general corrosion. In addition although the position of the welds was plainly obvious as a depression on the internal bore of the tube, the depression still showed the grinding marks from the time after welding when the weld was flushed. This clearly indicated that the welds had not

corroded during testing, thereby creating significant confidence in CuNiCr corrosion performance and weld corrosion performance.

Further tests have been carried out using a conical CuNiCr header, on the exhaust side of a Titanium heat exchanger, which was being tested on a flow rig. The Titanium tube plate of the header was coated with a plastic. The header contained two small weld repaired areas deposited using the same CuNiCr consumable used in the silencer trial. In addition to the weld repaired areas a number of steel plugs were let into the header wall and flushed off. The steel plugs were used to determine the extent to which a galvanic cell would be set up under these conditions.

After 15000hrs under test the system was disassembled and the internal surface of the conical header examined for evidence of corrosion. The main internal surface of the header showed no evidence of general corrosion. The weld areas were covered in a blue deposit. When the deposit was removed the weld surface was seen to have been uniformly corroded to depth of about 1mm. The blue deposit was also present over the area around the steel inserts. The area immediately around the steel inserts was seen to be corroded preferentially to the iron insert, to a depth of 1mm and for about 2mm away from and around the circumference of the insert.

Discussion

The successful production of a number of small items and a return end SW/FW heat exchanger header, at two copper base alloy foundries, has demonstrated that CuNiCr material can be reliably manufactured. The material delivered meets all the required mechanical properties, is chemically compliant and the castings are free from the non metallic defects occasionally seen with the material.

The corrosion tests carried out on the welded silencer clearly indicate that both the weld metal used and the material of the casting are not prone to corrosion under turbulent flow conditions and at the flow velocities used in service. Although the weld metal used in the GMA welds was very low in iron, this has not resulted in any impingement attack, even though it is generally recognised that CuNi requires some 0.7%Fe to be immune from this type of attack.

There are a number of reasons for the performance seen, one of which is that the welds are small and consequently, because of the of the cooling rate, the deposit is harder than would be normally expected. Secondly, because the alloy contains some 1% Cr, the chromium may be acting as an iron equivalent, thus preventing impingement attack.

The performance of the welded conical header is more difficult to understand. Unfortunately, the blue deposit was removed to examine the weld, before samples of the deposit could be taken for analysis, and thus the material has not been identified to date. However the deposit would be expected to be a copper compound, possible a hydrated chloride or oxychloride. No reason for the increased corrosion susceptibility of the weld deposit has been suggested. The corrosion potential of the cast alloy and the weld metal in sea water should not be significantly different, as the compositions are very similar. Similarly the presence of the Titanium tube plate and tubes should also not directly affect the corrosion performance, as the tube plate has been coated with an inert plastic material. However metallurgically, the casting and the weld deposit will be very dissimilar. The fact that there is preferential attack on the CuNiCr alloy around the circumference of the steel inserts is also puzzling, as it would indicate that the CuNiCr is

anodic to the iron, which is at variance with the position of ferritic iron copper base alloys in the electrochemical series.

Conclusions

Castings in CuNiCr can be made successfully, including ones of 1-1.5tons, for use as heat exchanger headers

EB and GMA welds, in a silencer tube, have shown excellent corrosion performance when subjected to turbulent flow at 1.5m/sec for 5,000hrs. This performance was predated by 10,000hrs in laminar flow at the same flow rate.

It is necessary to determine the cause of the unusual behaviour of the alloy, when used as a conical heat exchanger header, in order to develop the necessary confidence to put the alloy into service. The blue deposit, observed on the GMA welds, has not been identified and the apparent anodic behaviour of the CuNiCr, adjacent to the iron inserts, needs investigation.

It is now necessary to repeat the testing with iron containing and low iron weld deposits using both test rigs in order effectively investigate the observed phenomena.

References

1. Rowlands J C. Studies on the Preferential Phase Corrosion of Cast Aluminium Bronze in Sea Water. 8th International Congress on Metallic Corrosion. Mainz. 6th-11th September 1981.
2. Hall B N and Townsend W D. Further Experience with Cast CuNiCr (NES 824). 9th International Corrosion Conference. U.S. Naval Post Graduate School, Monterey, California. 6th-10th April 1992.

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Material Analysis
Castings

Element	Nickel Aluminium Bronze	Copper Nickel Chrome	CuNiCr Welding Consumable
Alloy			
Nickel	4.5-5.5	29.00-32.00	29.00-32.00
Aluminium	8.8-9.5		
Iron	4.0-5.0	0.5-1.0	
Manganese	0.75-1.3	0.5-1.0	1.4-2.0
Chromium		1.6-2.0	2.0-2.4
Silicon		0.20-0.40	0.20-0.40
Zirconium		0.05-0.15	0.05-0.15
Titanium		0.03-0.15	0.1-0.2
Copper	Remainder	Remainder	Remainder
Impurities			
Iron			<0.05
Zinc	<0.05		<0.0020
Lead	<0.01	<0.005	<0.0015
Tin	<0.05		
Silicon	<0.10		
Magnesium	<0.05		
Chromium	<0.01		
Phosphorus		<0.005	<0.005
Bismuth		<0.001	<0.0005
Sulphur		<0.001	<0.003
Carbon		<0.020	<0.006
Cobalt		<0.050	<0.020
Boron		<0.001	<0.001
Selenium			<0.0005
Tellurium			<0.0005
Arsenic			<0.0010

TABLE 1.

Schematic of CuNiCr Silencer
Test Piece

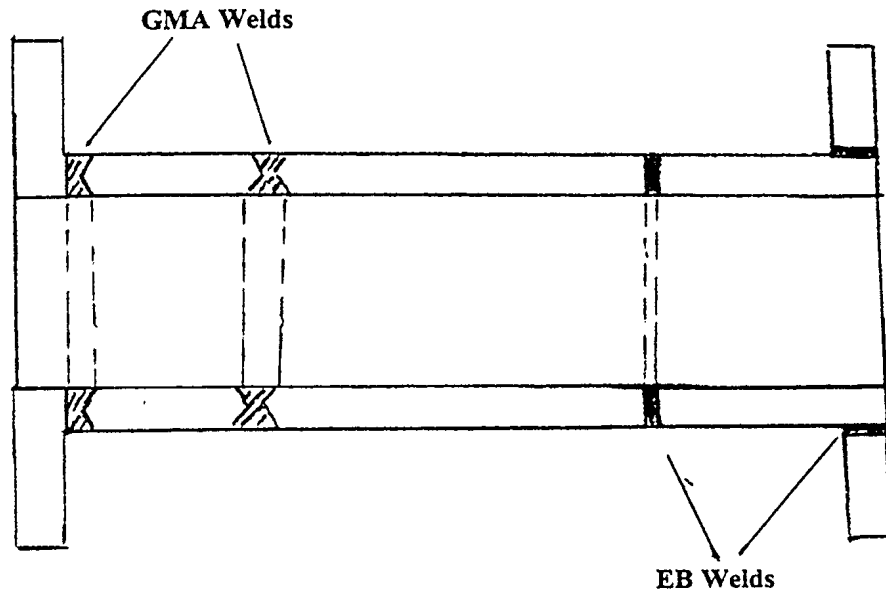


Figure 1.

