Copper Nickel Chromium for Marine Applications

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ABSTRACT

The use of a Copper Nickel Chromium Alloy to replace the current Nickel Aluminum Bronze in naval seawater systems and other marine applications is being pursued in the UK. This has been principally implemented to avoid the selective phase corrosion problems encountered in NAB, but other advantages may exist. This paper will present details of recent studies conducted in the UK on the Copper Nickel Chromium alloy to NES824.

A series of full sized cast components have been procured to confirm the supply of seawater system components. The acceptability of these components for naval use has been established through chemical analysis, mechanical property tests and non destructive testing. Destructive evaluation of one component has been conducted to compare properties with the test bars separately cast but used in the acceptance documentation.

INTRODUCTION

The background to high strength copper nickel alloys stem from the work conducted on these alloy types in the 1960's. It was at this time that the use of gunmetal castings for submarine seawater systems was questioned. Gunmetal suffered from corrosion problems and was not really adequate with respect to the 0.2% proof stress requirement. Consequently the various components made in this alloy tended to be heavy and thus the shock resistance was questionable, especially the inherent toughness which was not ideal. These concerns regarding the strength and particularly the shock resistance of the gunmetal castings employed in submarine seawater systems prompted the search for a replacement alloy.

High strength copper nickel alloys with resistance to seawater corrosion were under development with a view to developing an all welded seawater system of castings and pipes. However, concerns over the weldability of these copper nickel alloys and other varied reasons led to the eventual selection of nickel aluminium bronze (NAB) as the replacement for the gunmetal castings at that time.

In the 1970's NAB castings were found to be suffering from severe selective phase attack after relatively short periods of service in submarine seawater systems. This occurred in the cast matrix but was more severe in the heat affected zones of the welds. Welding had been used to fabricated complex structures or to repair defective regions of the castings. Amendments to the NAB material specifications, particularly heat treatments, were made to improve the material and HAZ performance, and welding on the wetted faces was restricted. This has enabled the seawater systems to be effectively managed in recent years. However management of the system is tiresome, labour intensive and costly. 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.

Developments in welding techniques, such as low heat input welding, to control the HAZ microstructure and size, have helped but their control is costly and effectiveness still questionable. Developments in NDE techniques and procedures for the detection of selective phase corrosion have been progressed but are not yet effective in the inspection of in-service items in situ. Seawater systems must be dismantled for revalidation.

HIGH STRENGTH COPPER NICKEL ALLOY

There was understandably a renewed interest in an alternative material, particularly to reduce the overall maintenance costs of these seawater systems. A review of candidate materials, based on strength, corrosion resistance and shock behaviour, identified niobium and chromium strengthened copper nickel alloys as leading contenders. After some further development the chromium alloy, with reportedly greater resistance to impingement attack and slightly superior weldability, won the vote. This alloy, specified in NES824, became the selected alternative to NAB in the mid 1980s, for use in future submarines and at refit.

Considerable work was conducted on the castability of this alloy prior to commercial procurement of components, and recommendations on methodology were prepared. This was instigated to avoid the procurement problems encountered when NAB components were initially purchased and casting problems encountered by some foundries.

Despite these actions the first commercial NES824 castings showed the existence of what were described as linear defects, particularly in the larger castings. These linear defects have been attributed to the casting methodologies utilised by the suppliers. The defects were large entrapped oxides formed as a result of inadequate control and turbulence during casting. Mechanical properties of specimens containing these defects clearly showed the defective material to have effectively no strength. They needed to be considered as a potential starter crack in fracture mechanics based safety analyses, although the inherent toughness of the material usually prevented any crack extension occurring in practical fracture and fatigue testing. These oxide films were originally very difficult to identify. They were not detected by radiography, and only found by dye penetrant inspection when surface breaking. This posed problems, with defects only being identified when final machining actions were undertaken. An eddy current technique has now been developed to reliably identify such defects in the surface layer.

The presence of these linear defects delayed the introduction of the material into many new or refitted systems. Components with defects were initially quarantined, prior to revalidation when the inspection techniques were developed and acceptance criteria were reviewed. NAB components continued to be procured and utilised in the seawater systems.

COPPER NICKEL CHROMIUM COMPONENT EVALUATION

The two foundries approved for the supply of NES824 castings closed in 1994 preventing any further procurement of this material. To re-establish a procurement route, a review of copper alloy foundries in the UK was undertaken to determine candidate foundries for the future production of NES824 castings. Foundries were invited to tender for the production of five castings representing typical submarine designs in NES824, with the aim of proving their capability to supply to Class 1 standards. Three suppliers were contracted to supply the castings which covered a range of different sizes, ranging from 100-200 pounds to 1-1.5 tons. The components supplied were independently evaluated and assessed by DERA.

Each of the three foundries selected supplied an inlet T piece, a valve body, a filter body, a hull valve body, an inlet/outlet header and four test plates. The castings were to be in copper nickel chromium alloy to NES 824 Part 1 Issue 3. Three bars for tensile testing and an analysis sample were also cast for each separate melt used.

Each casting was evaluated by DERA against the requirements of NES 824 Part 1 Issue 3 for chemical composition, mechanical properties and structural integrity by non-destructive testing.

Chemical Composition

It has been identified that the chemical analysis of this material is not a simple matter. Considerable uncertainty in absolute composition existed in earlier studies. To facilitate conformance to the NES824 specification a number of analytical standards have been specially prepared for MoD to ensure that whatever the analytical method used it can be calibrated by use of the standard samples. For this independent evaluation the methods used were: X-ray fluorescence against standards for Ni, Cr, Fe, Mn, Si, Zr, Ti, P, and Co; inductively coupled plasma for B; furnace atomic absorption for Pb and Bi; combustion using carbon-sulphur analyser for C and S. The results of these analyses were compared with the chemical composition specified by NES 824 Part 1 Issue 3 in Table 1.

There were some indications of chemical compositions being outside the NES824 specification limits. In general, the extent of the differences in the analyses is to be expected. It has been shown that compositional variation in cast copper nickel chromium to NES824 will occur due to dendritic 'coring' and that nickel, chromium, iron, manganese, silicon and copper levels can vary considerably. Similarly, despite the use of the analytical standards, different test methods can still generate different compositional results. However, some results were clearly shown to be outside the limits for certain elements by a large amount. Two analytical samples from one supplier appeared to be supplied without Zr and Ti additions. One sample was found to have three times the phosphorous limit and another twice the boron limit. Confirmatory tests on the actual castings may be possible in future.

Mechanical Properties

The three cast bars supplied from each casting were machined into tensile test pieces and tested in accordance with BS EN10002. The average values of room temperature Ultimate Tensile Strength (UTS), 0.2% Proof Stress (PS) and % Elongation compare with the specification values are presented in Table 2.

The mechanical properties determined showed individual test UTS values ranging from 500 to 584 MPa, 0.2%PS values from 319 to 387 MPa, and elongations from 16 to 24% across the tests conducted on each of the 15 casts. It is not surprising that some variation in elongations were observed given the large grain size existing in some of the test bars.

Subsequent work on an inlet T piece has enabled the testing of the tensile properties of the actual component for comparison with the results from the test bars from the same cast. It has long been a concern that the results from these test bars do not truly represent the cast component which are invariably lower being part of a larger casting. The results obtained from flange and body specimens are compared with the test bar results in Table 3.

The values obtained to date confirm these concerns and have results below those within the specification. From fractography the lower strength values have been found to be associated with areas of shrinkage and interdendritic porosity within the test specimens machined from the component.

Whilst it is evident that the UTS and 0.2% PS properties of the specimens machined from the actual casting are slightly below the material property minima stated in the NES, it must be considered that the 0.2% PS for this material is greater than the 270 MPa value for NAB which it is planned to replace. (This NAB figure is itself based on test bars and there is evidence that actual castings in this material also shows reduced property levels.) It is likely that within the casting there would be a range of properties dependent on such aspects as section size, casting methodology, grain size, etc. Some areas being above and a few below the specified minima. Sufficient safety factors are used in the design of these components to allow for this observed reduction in tensile behaviour.

Non Destructive Evaluation

Each casting was subjected to non-destructive examination by each supplying foundry in accordance with the current NES 824 Part 1 specification requirements. This covered liquid penetrant examination, eddy current inspection and radiographic examination. The NES allows for a degree of rectification of defects. In this trial a condition of the contracts was that no weld repairs were to be conducted but castings rejected by the foundry but considered repairable in accordance with the NES could be supplied

Defects identified by the three NDE techniques used were reported by the suppliers in some castings but they considered them acceptable or rejectable but repairable within the specification e.g. linear defects revealed by liquid penetrant inspection of an inlet/outlet header, a surface breaking defect revealed by eddy current inspection of an inlet T piece, and shrinkage identified by radiography in a valve body and header. There was general agreement in the interpretation of the radiographs by the foundries and the independent assessor. Although one supplier sent components with known defects that he deemed repairable but some of these were rejected by the independent assessor. In a true procurement scenario the supplier would be conducting the weld repair and to conduct this he would be grinding out the defect and would be able to confirm whether the casting was actually acceptable at that point.

It is planned that some of these casting will be used in the development and evaluation of weld repair techniques and these studies will confirm the acceptability of these types of components.

CONCLUSIONS

The reported studies have been part of an exercise to re-establish an UK production base for submarine seawater system components manufactured in the copper nickel chromium alloy to NES824.

The assessment has shown that acceptable castings over a range of sizes can be supplied that conform to the requirements of NES824 Part 1 Issue 3.

The cost benefits and improved corrosion performance identified in the use of this copper nickel chromium alloy for submarine seawater systems can now be realised in future RN vessels and in current vessels at refit.

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Chemical Composition

		Ni	Cr	Fe	Mn	Si	Zr	Ti	Cu
NES824 Part 1 Issue 3	min	29.00	1.6	.5	.5	.20	.05	.05	---
	max	32.00	2.0	1.0	1.0	.40	.15	.15	rem

		Pb	P	Bi	S	C	Co	B	Total Impurities
NES824 Part 1 Issue 3	min	---	---	---	---	---	---	---	---
	max	.005	.005	.001	.005	.020	.050	.001	.070
	target max	.0015		.0005	.0030	.006			

		Se	Te	As	Zn
NES824 Part 1 Issue 3	target max	.0005	.0005	.0010	.0030

Table 1. Chemical composition requirements from NES824 Part 1 Issue 3.

Casting	Supplier	Tensile Strength (UTS) MPa	0.2% Proof Stress (PS) MPa	Elongation %
		Mechanical Properties		
Inlet T Piece	A	529	351	18
	B	584	386	21
	C	521	338	20
Valve Body	A	525	342	21
	B	543	352	22
	C	528	347	21
Filter Body	A	547	362	21
	B	551	355	20
	C	528	347	21
Hull Valve Body	A	529	342	21
	B	531	344	21
	C	504	331	19
Inlet/Outlet Header	A	562	383	18
	B	543	366	18
	C	507	331	19
NES824 Pt1 Iss3		480 min	300 min	18 min

Table 2. Mechanical properties of cast test bars.

COMPONENT	UTS MPa	0.2% PS MPa	% Elongation
Test Bar	516	351	16.5
	535	350	19.5
	537	352	19.5
Ave	529	351	18.5
Casting Flange	445	296	14.1
	411	295	18.0
Ave	428	295.5	16.0
Casting Body	459	287	23.1
	481	294	27.3
Ave	470	290.5	25.2
NES824 Pt1 Iss3	480 min	300 min	18 min

Table 3. Comparison of tensile properties of inlet T piece test bars and actual casting.