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The corrosion of nickel–aluminium bronze in seawater

J.A. Wharton [a,*], R.C. Barik [a], G. Kear [b], R.J.K. Wood [a], K.R. Stokes [a,c], F.C. Walsh [a]

[a] *Surface and Electrochemical Engineering Groups, University of Southampton, School of Engineering Sciences, Highfield, Southampton SO17 1BJ, United Kingdom*
[b] *BRANZ Ltd., Science and Engineering Services, Private Bag 50 908, Porirua City, Wellington 6220, New Zealand*
[c] *Physical Sciences Department, Dstl, Porton Down, Salisbury, Wiltshire SP4 0JQ, United Kingdom*

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Abstract

Nickel–aluminium bronze (NAB) alloys show good corrosion resistance under marine conditions. The corrosion behaviour of cast and wrought NAB alloys is illustrated in this work through a range of electrochemical techniques including open-circuit potentiometry with time, oxygen reduction voltammetry, NAB dissolution voltammetry, potential step (or flow step) current transients and linear polarisation resistance. The galvanic coupling of NAB to stainless steel or copper is examined by zero resistance ammetery. The importance of using controlled flow working electrodes is illustrated by the use of a rotating disc electrode, a rotating cylinder electrode and a bimetallic (NAB/copper–nickel) rotating cylinder electrode. In addition to controlling the hydrodynamics, such electrodes allow charge transfer data to separate from those of mass transport control under mixed kinetic control. Longer term seawater immersion trials on planar coupons coupled to titanium or cupronickel are also reported. The relative contributions of erosion and corrosion attack are considered using a wall-jet electrode and the corrosion characteristics of NAB are compared to those of copper and copper–nickel in chloride media.

* Corresponding author. Tel.: +44 23 8059 2890; fax: +44 23 8059 3016.
E-mail address: jaw6@soton.ac.uk (J.A. Wharton).

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1. Introduction

Aluminium bronzes are copper-based alloys in which aluminium (<14 wt.%) is the main alloying element. In addition, some of the alloys contain iron, nickel, manganese or silicon. Both cast and wrought aluminium bronzes offer a good combination of mechanical properties and corrosion resistance. Consequently, aluminium bronzes have been widely used for decades in a variety of marine applications, including valves and fittings, ship propellers, pump castings, pump shafts, valve stems and heat exchanger waterboxes [1].

Nickel–aluminium bronze (NAB) alloys containing 9–12 wt.% aluminium with additions of up to 6 wt.% each of iron and nickel represent one of the most important groups of commercial aluminium bronzes. Increasing aluminium content results in higher strength, which is attributable to a hard face-centred cubic (fcc) phase which enhances the properties of castings as well as hot working in wrought alloys [2]. The other alloying elements also improve properties and alter microstructure. Nickel improves corrosion resistance, while iron acts as a grain refiner and increases tensile strength. Nickel also improves yield strength, and both nickel and manganese act as microstructure stabilisers [2]. Table 1 shows the composition of the main commercial alloys: CuAl10Fe5Ni5, CuAl10Ni5Fe4, CuAl11Ni6Fe6 and CuA19Ni5-Fe4Mn. NAB alloys are metallurgically complex alloys with several intermetallic phases in which small variations in composition can result in the development of markedly different microstructures [2–4], which can result in wide variations in seawater corrosion resistance. The microstructures that result in optimum corrosion resistance can be obtained by controlling the composition and heat treatment [5]. For example, castings of CuA19Ni5Fe4Mn used for naval applications are given an annealing treatment at 675 °C for 2 to 6 h [2].

The microstructure of a sand cast NAB (Fig. 1a) consists of light etched areas of α-phase, which is a fcc copper-rich solid solution and dark etched martensitic regions (‘β-phase or retained β’-a high temperature phase), surrounded by lamellar eutectoid phases and a series of intermetallic κ-phases. The κ_I-phase is globular or rosette shaped and is reported to be iron-rich (based on Fe_3Al). The κ_{II}-phase also takes the form of dendritic rosettes which are unevenly distributed at the α/β boundary and are smaller than the κ_I rosette. The κ_{III}-phase can appear in either a lamellar or sometimes a coagulated or globular (degraded lamellar) form. It grows normal to the α/β boundary, as well as forming at the boundary of the large κ_I-phase, and is described as being nickel-rich (NiAl). The κ_{IV}-phase is a fine precipitate within the α-phase and is considered to be iron-rich. The microstructure perpendicular to the extrusion direction for the wrought NAB bar is shown in Fig. 1b). The microstructure has been influenced by the extrusion with little evidence of the β and κ_{III}-phases. The heat treatment specified for the NES747 Part 2 British Naval