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Corrosion behavior of leaded-bronze alloys in sea water

K.M. Zohdy [a, *], M.M. Sadawy [b], M. Ghanem [c]

[a] Higher Technological Institute, 10th of Ramadan City, Egypt
[b] Mining and Petroleum Engineering Department, Al-Azhar University, Nasr City, Cairo 11371, Egypt
[c] Industrial Education, Suez University, Egypt

HIGHLIGHTS

- The corrosion potential of leaded bronze shifts to more noble potential.
- The corrosion resistance increases with increasing amount of copper content in leaded bronze alloys.
- The patina formed on Cu–5Sn–5Zn–5Pb is more uniform and protective than other alloys.
- The composition of patina formed on leaded bronze depends on the concentration of Cu, Sn, Zn and Pb in the alloy.

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ABSTRACT

The corrosion behavior of leaded-bronze alloys (Cu–5Sn–5Zn–5Pb, Cu–8Sn–8Zn–8Pb and Cu–10Sn–10Zn–10Pb) in sea water was investigated using weight loss method, open-circuit potential measurements (OCP), polarization techniques and electrochemical impedance spectroscopy (EIS). The nature and morphology of the corrosion products were investigated by scanning electron microscopy (SEM) and X-ray diffraction (XRD). The results showed that the corrosion resistance decreases with decreasing copper content. The XRD indicated that the composition of patina depends on the concentration of Cu, Sn, Zn and Pb in each alloy.

1. Introduction

Bearings are used to prevent friction between parts during relative movement. In machinery they fall into two primary categories: anti-friction or rolling element bearings and hydrodynamic journal bearings. The primary function of a bearing is to carry load between a rotor and the case with as little wear as possible. This bearing function exists in almost every occurrence of daily life from the watch on your wrist to the automobile you drive to the disk drive in your computer. In industry, the use of journal bearings is specialized for rotating machinery both low and high speed [1–3]. Copper alloys have long been used for bearing because of their combination of moderate-to-high strength, corrosion resistance and self-lubrication properties [4–6].

The addition of lead (Pb) to copper alloys, improves the alloys sliding properties without the negative influence on their heat conductivity. Cu–Pb system is characterized by partial solubility only in a liquid state and absolute insolubility in a solid state. The resulting structure, after solidification, consists of copper and lead crystals. At a high cooling rate both alloy components are uniformly distributed and the alloys have very good sliding properties. Leaded bronzes are suitable for steel friction bearing shells. They endure high specific presses, quite high circumferential speeds and it is possible to use them at elevated temperatures (around 300 °C) [3,6,7]. Since lead is practically insoluble in copper, a cast copper–lead microstructure consists of lead pockets in a copper matrix. These pockets of lead serve as reservoirs for maintaining a continuous lead film on the bearing surface [3,6,7]. The 4–10% tin content in leaded bronze increases strength, maximum load capacity, fatigue resistance, and hardness above what is available with simple copper lead alloys. Zinc is sometimes used as a replacement for tin, and nickel or silver. It is often added to improve corrosion resistance and toughness [3,6,7].

* Corresponding author.
E-mail addresses: khalzohdy@yahoo.com, drkhaledzohdy@yahoo.com (K.M. Zohdy).

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The electrochemical behavior of Cu alloys have been studied extensively over a wide range of experimental conditions to explore different processes such as dealloying, stress corrosion cracking, passivation, and pitting corrosion [8–20]. However, there are few references in literature that report the study of Cu–Sn–Zn–Pb alloys with high contents of lead in an atmosphere rich in chlorine. Hence the investigation of corrosion behavior of Cu–Sn–Zn–Pb alloys under sea water conditions is very meaningful.

2. Experimental work

2.1. Material

The present study was carried out using three different alloys of Cu–Sn–Zn–Pb which were fabricated from high purity Cu, Sn, Zn and Pb. A measured weight of Cu was placed into a silica crucible and melted at 1200 °C. The appropriate amounts of Sn, Zn and Pb were then added and mechanically stirred for 5 min. Schematic operational sequence during melt stirring is shown in Fig. 1. The melt is then casted into steel mold of dimensions (200 × 50 × 20 mm) and naturally cooled down to room temperature. The chemical composition of the specimens was determined by X-ray fluorescence (XRF) analyses and tabulated in Table 1. Discs about 0.7 cm in diameter and 2 mm thick were cut from the ingot using disc cutter. The discs were mechanically polished using SiC emery paper of grades 300–1200 mesh and diamond paste. Specimens were etched by using 10 volume concentrated NH_4OH and 1 volume H_2O_2 (3 per cent solution). The microstructure of specimens before corrosion was examined with the optical microscope.

2.2. Weight loss method

Standard immersion tests were carried out according to ASTM G1 and G31 [21]. Specimens were cut into cylindrical coupons for immersion tests. Before exposure, the samples were mechanically polished using wet SiC paper (initially 400, 500, 800 and 1200 grades and lubricated using distilled water). The polished samples were cleaned with acetone, washed using distilled water and dried in air. The samples were weighed before exposure by means of an analytical balance for the original weight (W_0) and then hung in test solutions. After immersion, the corroded specimens were removed from the solutions, cleaned with HCl solution for 3 min and dried. Finally, the coupons were weighed again in order to obtain the final weight (W_1).

2.3. Electrochemical technique

All electrochemical experiments were conducted with a Gamry PCI300/4 Potentiostat/Galvanostat/Zra analyzer. It was connected to a PC. The Echem Analyst software (version 5.21) was used for all electrochemical data analysis. A three-electrode cell composed of a specimen as a working electrode, Pt counter electrode, and saturated calomel electrode as a reference electrode were used for the tests.

Tafel polarization tests were carried out using a scan rate of 0.5 mV min^{-1} at 25 °C. Specimens with exposed surface area of 1.0 cm^2 were used as a working electrode. Prior to electrochemical tests, the specimens were cathodically cleaned for 15 min at −1500 mV (SCE) to remove the air-formed oxide film. The

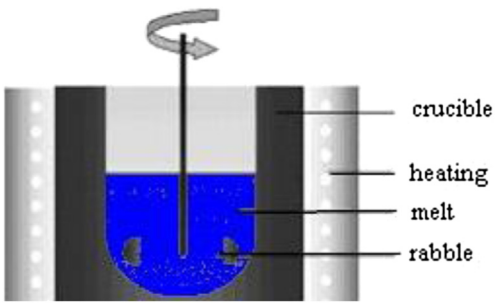

Fig. 1. Schematic operational sequence during melt stirring.

Table 1
Chemical composition of the prepared Cu–Sn–Zn–Pb alloys (wt %).

Designation	Sn	Zn	Pb	S	Cu
Cu–5Sn–5Zn–5Pb	5	5	5	<0.002	Bal.
Cu–8Sn–8Zn–8Pb	8	8	8	<0.002	Bal
Cu–10Sn–10Zn–10Pb	10	10	10	<0.002	Bal

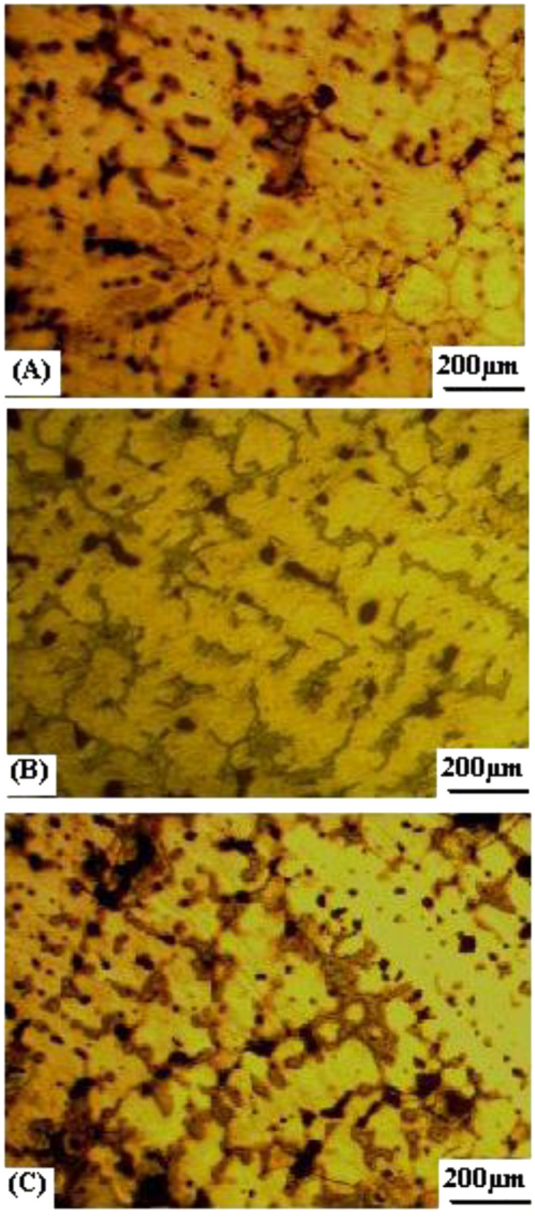

Fig. 2. Microstructure of leaded bronze (A) Cu–5Sn–5Zn–5Pb, (B) Cu–8Sn–8Zn–8Pb and (C) Cu–10Sn–10Zn–10Pb.