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Electrochemical deposition of Al–Mg alloys on tungsten wires from $AlCl_3$–NaCl–KCl melts

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HIGHLIGHTS

- The method of electrochemical deposition is used to prepare Al–Mg alloys on tungsten wires.
- $AlCl_3$–NaCl–KCl melts as a non-aqueous electrolyte is used in electrochemical deposition.
- The effects of deposition voltage and molten salt temperature on the surface morphology and magnesium content of the Al–Mg deposits are studied.
- Al–Mg alloys with 9.14 at.% Mg are obtained.

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ABSTRACT

This paper studies the electrochemical method that obtains the Al–Mg alloys on tungsten wires from $AlCl_3$–NaCl–KCl melts containing a mass fraction of 3% $MgCl_2$. Electrochemical experiments are performed with a three electrode system. Linear sweep voltammetry is used to determine the electrodeposition potential of Al–Mg alloys in molten salts. X-ray diffraction is employed to examine the crystallographic structure of Al–Mg alloy electrodeposits. Results show that the Al–Mg alloy coating consists of an Al (Mg) solid solution and the amorphous phase. The effects of the electrodeposition potential and temperature on the morphology of Al–Mg electrodeposits are demonstrated by scanning electron microscopy.

1. Introduction

As reported, the target chamber load is the key part in the Z-pinch driven inertial confinement fusion (ICF), which determines the rate of the converting laser light to the X-ray conversion [1,2]. A wide variety of cylindrical Z-pinch loads, including thin annular foils, gas puffs, low-density foams, and low-number wire arrays, have been used in early experiments. A dramatic breakthrough in X-ray power was achieved in 1995 [3], and tungsten wire has been widely applied in Z-pinch physical experiments [4,5].

Al–Mg alloys are excellent lightweight metallic materials because of their attractive properties, such as high volumetric heat content, high specific strength, high specific stiffness, low density, and strong corrosion resistance [6]. Therefore, Al–Mg alloy wire arrays are also one of the most common materials applied in Z-pinch physical experiments. As previously reported [7–9], a mixture of aluminum and magnesium is observed to maximize the radiated kilovolt X-ray yield at 50 kJ, which is 1.5 times higher than that obtained with pure aluminum [7]. The mixed Al–W array load can emit equivalent X-ray pulses as the W array load, but the intensity of the X rays pulses is lower than that of pure Al wire array [10]. Magnesium is more active than aluminum. Al–Mg alloys have the advantages of excellent electrical conductivity and thermal conductivity. A higher yield of X rays can be obtained by eletrodepositing Al–Mg alloys onto tungsten wire surface as wire arrays load.

The reduction potentials of Al and Mg (−1.706 V for Al and −2.375 V for Mg) are more negative than that of water for hydrolysis [11]. Therefore, aqueous electrolytes can-not be used for the electrodeposition of Al–Mg alloys. Al, Mg, and their alloys have been obtained from non-aqueous electrolytes [12–15]. The electrodeposition of Al–Mg alloys from an organic solvent has limitations, such as poor stability, high toxicity, and heavy pollution. The molten salt system is relatively simple, economical, and environment friendly.

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In particular, inorganic molten salts can dissolve various metal salts, which are ideal for various metal electrodeposition process.

As previously reported in 2000 [16–22], the Mg atomic ratio during the electrodeposition of Al–Mg alloys was less than 2.2 at.% from the acidic $AlCl_3$–EMIC melts containing $MgCl_2$ [16]. In 2010, the aluminum-alloyed coating on AZ91D magnesium alloys was obtained from their molten salts containing $AlCl_3$ at lower temperatures. Previous results showed that aluminum-alloyed coating consists of Mg_2Al_3 and $Mg_{17}Al_{12}$ intermetallic compounds [17]. The Al–Mg alloys were also electrodeposited by an organometallic-based electrolyte with $Na[AlEt_4] + 2\ AlEt_3 + 3.3$ toluene as the electrolyte [19], this previous study was only able to obtain a maximum of approximately 24 wt.% Mg in the alloys.

In the present paper, Al–Mg alloys on tungsten wires are obtained from $AlCl_3$–NaCl–KCl melts (by a Al:Na:K mole ratio of 61:26:13) containing a mass fraction of 3% $MgCl_2$. SEM analysis also investigated the effect of the electrodeposition potential, temperature on the morphology of Al–Mg electrodeposits.

2. Experimental

2.1. Preparation and purification of melts

All chemicals are of analytical-grade. Magnesium chloride and aluminum chloride must be used in a dry environment because of their easy moisture absorption. The aluminum chloride regent bottle is wax sealed. The fine powder of sodium chloride and potassium chloride is heated for 8 h at 300 °C in the muffle furnace to remove moisture [23]. Magnesium chloride is placed in a drying oven at 80 °C for 24 h. A mixture of $AlCl_3$–NaCl–KCl melts is obtained with a Al:Na:K mole ratio of 61:26:13 [19]. Magnesium chloride at a mass (total mass of $AlCl_3$–NaCl–KCl powder) fraction of 3% is added into the $AlCl_3$–NaCl–KCl powder. After weighing, the mixed powder is gently shaken to mix it evenly. The glass beaker containing the mixed powder is placed in an argon atmosphere for 20 min. When the oil bath reached the required temperature ($T = 180$, 200, and 220 °C), the glass beaker is immersed into the bath. The power was melted under the argon atmosphere until the mixture turned into a brown liquid.

2.2. Electrochemical apparatus and electrodes

Electrochemical experiments are performed using Metrohm Autolab B.V. electrochemical workstation (PGSTAT302N, Netherlands) with a three electrode system. The working electrode is tungsten wire (99.95%). The counter electrode is a platinum wire electrode (99.99%). The reference electrode is a silver electrode.

First, the W electrode is successively polished by SiC emery paper with grits of 500, 1000, and 2000 to obtain a smooth surface before electrochemical measurements. After fully cleaned in an ultrasonic bath for 5 min and dried by thin cool air, the W electrode is immersed in the solution (NaOH, 25 g L^{-1}; Na_2CO_3, 50 g L^{-1}; Na_3PO_4, 40 g L^{-1}) for 10–15 min to remove oil stains and tungsten oxide in an ultrasonic cleaner. Then, Ag reference electrode is immersed in 0.1 mol L^{-1} HNO_3 for a few seconds to remove the oxide. Both the W electrode and the Ag electrode are cleaned with deionized water and ethanol. The platinum wire electrode is cleaned with laboratory detergent and deionized water. Finally, after drying in clean cool air, the three electrodes are directly immersed into the molten salts. Data are collected by the electrochemical workstation.

2.3. Electrodeposition of Al–Mg alloys

The substrates are tungsten (99.95%) wires. A cylinder-shaped aluminum foil electrode is used to surround the tungsten electrode, as shown in Fig. 1. The tungsten wires are cleaned as described in Section 2.2. However, the tungsten wires do not need to be

Table 1
Electrodeposition parameters used in this study.

Deposit #	E (V)	T (°C)
1	−1.20	200
2	−1.30	200
3	−1.40	200
4	−1.30	180
5	−1.30	220

E = deposition potential, T = temperature.

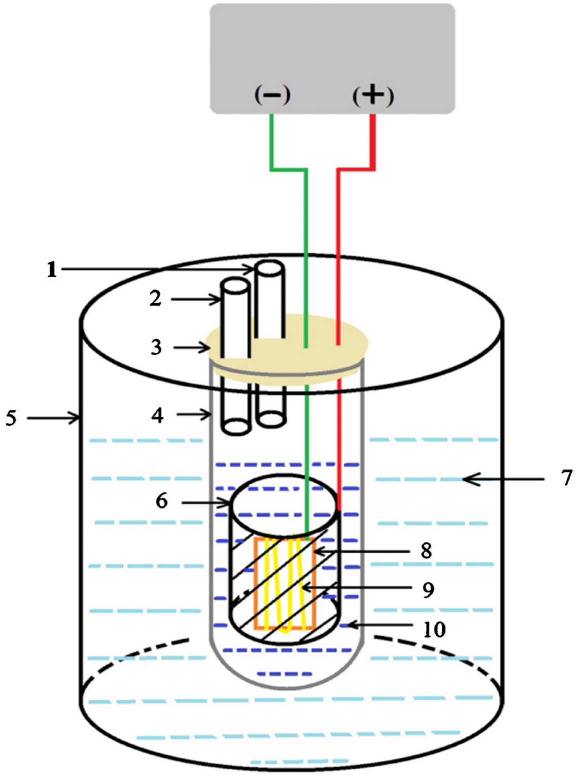

Fig. 1. A schematic diagram of experimental set-up: (1) air inlet; (2) air outlet; (3) rubber stopper; (4) glass beaker; (5) numerical show constant temperature oil-bathing; (6) aluminum foil; (7) oil; (8) PTFE; (9) tungsten wires; (10) molten salt.

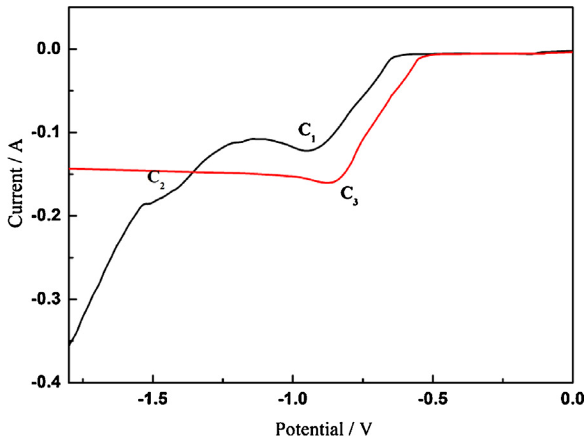

Fig. 2. LSV of the $AlCl_3$–NaCl–KCl melts at the scan rate 5 mV s^{-1} at 200 °C. (The red and black lines are the LSV curves of the electrolytes without $MgCl_2$ and with a mass fraction of 3% $MgCl_2$, respectively.) (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)