Corrosion Science xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Corrosion Science

journal homepage: www.elsevier.com/locate/corsci

Corrosion resistance of Al–Cu–Fe alloy powder coated with silica using an ultrasound-assisted sol–gel method

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ARTICLE INFO

Article history:
Received 24 December 2012
Accepted 8 April 2013
Available online xxxx

Keywords:
A. Aluminum alloys
C. Acid inhibition
C. Oxide coatings
B. Ultrasonics
B. Erosion

ABSTRACT

Al–Cu–Fe alloy powder, a high-effective lubrication oil additive, was coated by conventional sol–gel method employing tetraethoxysilane (TEOS) as the precursor for purpose of improving its corrosion resistance. The best condition was obtained according to an orthogonal experiment ($L_9(3^4)$). Then, the sol–gel method was modified by employing ultrasound to study the effects of both the ultrasonic power and irradiation time on the coating process. Finally, the coated powder had an high corrosion resistance in the acid media of pH 1. The obtained samples were characterised by FTIR, XRD, SEM and EDS.

1. Introduction

Quasicrystal has been widely applied for surface protection coating, due to their distinguished properties including low coefficient of friction, remarkable wear resistances, and high hardness [1], etc. It has been reported that the lubricating oil with Al–Cu–Fe alloy powder containing icosahedral quasicrystal [2] is able to greatly decrease the mechanical wear, improve the mechanical efficiency and finally reduce fuel consumption. (The lubricating mechanism of Al–Cu–Fe powder is as follows. Al–Cu–Fe particles can easily form an abrasion-resistant film on the surface of friction pairs at high temperatures and pressures when friction pairs are moved. The friction coefficient declines distinctly and finally fuel consumption reduces). However, the powder can easily react with trace amounts of water and acidic material in lubricating oil [3] and the equation is as follows:

$$2\text{Al} + 6\text{HCl} \rightarrow 2\text{AlCl}_3 + 3\text{H}_2 \uparrow$$

$$2\text{Fe} + 4\text{HCl} \rightarrow 2\text{FeCl}_2 + 2\text{H}_2 \uparrow$$

Therefore, it is essential to coat the Al–Cu–Fe alloy powder. It is reported that inorganic powder can be coated by numerous methods, such as precipitation of coating materials [4,5], graft polymerisation, admicellar polymerization [6] and microemulsion. Sol–gel method, which is easily achieved in a low reaction temperature, provides many advantages in coating complex shaped particles at the nanometer scale [7]. In addition, owing to the covalent bonding between the inorganic powder and the encapsulation layer, the sol–gel coating has a good adhesion to metallic substrates. Consequently, the sol–gel method is becoming one of the most effective methods to protect sensitive inorganic surfaces from potential degradation in their application environment [8–11]. Tetraethoxysilane (TEOS) is the most common precursor on account of its relatively slow and controllable rate of reaction [12]. For instance, recently some researchers [13–18] coated the aluminum flakes via the sol–gel method employing tetraethoxysilane (TEOS) as the precursor and got an good result. A fundamental problem often encountered in the sol–gel coating process is that a discontinuous coating with the undesirable colloidal particles is often produced. Although the condition is strictly controlled, it seems that colloidal particles are almost inevitable, which may be attributable to the limitation of mechanical stirring [19]. This paper tries to induce external forces such as ultrasonic irradiation to eliminate colloidal particles and obtain a uniform coating.

It is recognized that ultrasonic irradiation can create extraordinary physical and chemical conditions [20,21]. Thus, ultrasonic irradiation is expected to make differences in the coating process.

This paper shows that ultrasonic power and irradiation time have a great influence on the coating rate and morphology of silica coating. According to this paper, it is concluded that similar results will be found if ultrasonic irradiation is exploited to coating any other metal powder. In the present paper, we also investigate the effects of both the ultrasonic power and the irradiation time on the coating process. To our best knowledge, there is little research available on such studies.

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http://dx.doi.org/10.1016/j.corsci.2013.04.018

Please cite this article in press as: B. Liang et al., Corrosion resistance of Al–Cu–Fe alloy powder coated with silica using an ultrasound-assisted sol–gel method, Corros. Sci. (2013), http://dx.doi.org/10.1016/j.corsci.2013.04.018

2. Experimental

2.1. Materials

Al–Cu–Fe alloy powder was dried under vacuum at 60 °C for 12 h after washing with ethanol. The rest of the materials were used as received. Raw materials are summarized in Table 1.

2.2. Al–Cu–Fe alloy powder coated using the conventional sol–gel method

Fig. 1 is an illustration of the procedure of coating the Al–Cu–Fe alloy powder. 2 g Al–Cu–Fe alloy powder and 30 g ethanol were poured into a flask fitted with an agitator. The slurry was stirred at 25 °C for 0.5 h. Then, two solutions were prepared: solution I (2 g TEOS + 18 g ethanol) and solution II {(0.25–0.99 g) ammonia + (1.73–6.91 g) water + (12.10–18.12 g) ethanol}. Solution I and II were added dropwise to the slurry simultaneously. After the dripping of solution I and II, the slurry was further stirred for a specified time range. Then, the coated powder was collected through ethanol cleaning and centrifuge. Finally, the powder obtained was dried in a vacuum oven at 60 °C for 12 h.

2.3. Al–Cu–Fe alloy powder coated using the ultrasound assisted sol–gel method

All of the following experiments were carried out under mechanical stirring and ultrasonic irradiation simultaneously with the optimal n_W:n_{TEOS}, n_A:n_{TEOS} and reaction temperature obtained from the above conventional sol–gel method. The flask, which contained the mixture of Al–Cu–Fe alloy powder, ethanol and ammonia, was placed in an ultrasonic bath (KQ-250DE, 40 kHz). In addition, feeding methods, stirring speed and collection procedures of samples were kept the same as those described in Section 2.2.

2.4. Characterization and testing

Fourier transformation infrared (FTIR) measurements were determined by a PerkinElmer Spectrum One FT-IR Spectrometer. X-ray diffraction spectra (XRD) were analyzed using a TongDa TD-3500. Scanning electron microscopy (SEM) and Energy dispersive spectroscopic (EDS) investigations were determined by a FEI Quanta-600 instrument. The average grain size (d_{50}) of Al–Cu–Fe alloy powder was obtained on a Malvern 2000 particle size analyzer.

The stability test was conducted to investigate the effect of coating obtained in this paper. 0.2 g coated or uncoated Al–Cu–Fe alloy powder was dispersed in HCl solutions of pH 1 at 50 °C for 12 h. The amount of gas generated was measured using a self-made gas collection equipment, as shown schematically in Fig. 2.

Table 1
Raw materials.

Materials	Grade	Manufacturer
Aluminum alloy powder	⩾99% d_{50} = 6.35 μm	Beihang university, China
Ammonia solution	25–28%[a]	Sinopharm chemical reagent Co., Ltd.
Tetraethoxysilane	⩾28.4%[b]	Sinopharm chemical reagent Co., Ltd.
Absolute ethanol	⩾99.7%	Tianjin damao chemical reagent Co., Ltd.

[a] NH_3 content.
[b] Silica content.

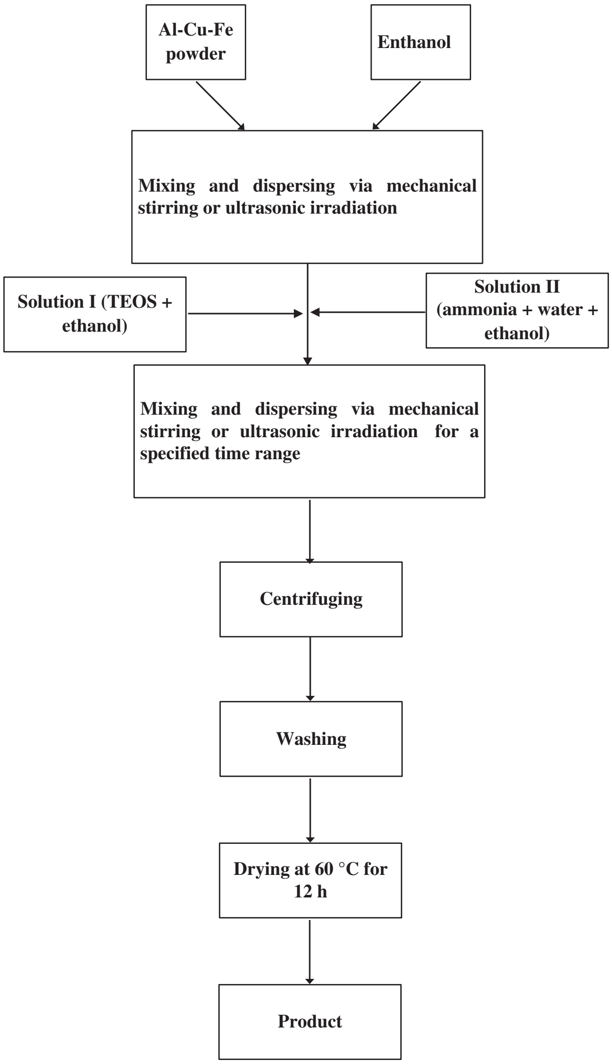

Fig. 1. Procedure of coating Al–Cu–Fe alloy powder.

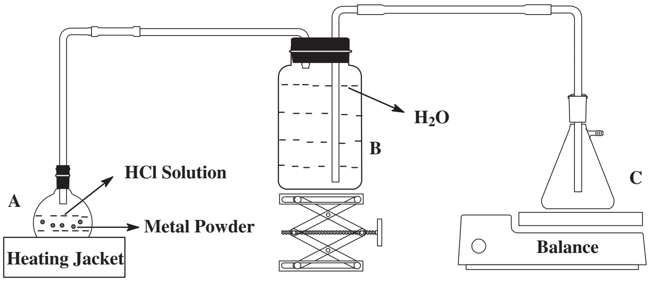

Fig. 2. Gas collection equipment. (Section A contains a sealed flask and coated Al–Cu–Fe alloy powder and HCl solution; Section B contains a sealed jar and distilled water; Section C contains an empty flask. The gas, which is generated from Section A during the test, will expel the distilled water in Section B into Section C).

Section A contains a sealed flask and coated Al–Cu–Fe alloy powder and HCl solution; Section B contains a sealed jar and distilled water; Section C contains an empty flask. The gas, which is generated from Section A during the test, will expel the distilled water in Section B into Section C. The gas volume evolved from Section A can be measured by the increased weigh in Section C. The corrosion protection efficiency (η,%) was calculated using the following expression [22,23]:

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