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Effect of Ce addition on microstructure, mechanical properties and corrosion behavior of Al-Cu-Mn-Mg-Fe alloy

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Abstract

The effects of rare earth Ce on the microstructure, mechanical properties and corrosion behavior of Al-Cu-Mn-Mg-Fe alloys were investigated by means of microstructure analysis, tensile test and electrochemical corrosion test. The research shows that the Al-Cu-Mn-Mg-Fe alloy after low temperature heat treatment mainly contains the S(Al2CuMg) phase, the T(Al20Cu3Mn)3 phase, the Al6 (Mn, Fe) phase and the Al12Cu5Fe phase, and the rare earth Ce makes the alloy form the new rare earth phase Al8Cu4Ce. The appearance of this phase has a significant refinement effect on the Al6 (Mn, Fe) phase. Compared with Ce-free, the yield strength and tensile strength of Al-Cu-Mn-Mg-Fe alloy with 0.254 ωt% Ce increased by 7% and 15%, respectively, and the elongation increased from 3.1% to 4.8%. It also has better corrosion resistance, which is represented by the decrease of corrosion current density and positive shift of corrosion potential in Tafel measurement in solutions of different concentrations, and the increase of corrosion impedance in electrochemical impedance spectroscopy test, especially the corrosion current density was reduced by 6.06 μA cm−2 in 3.5% NaCl solution.

1. Introduction

As an important part of electric vehicles, batteries are the root of electric vehicle power. Due to its high voltage, no memory effect and environmental pollution, high specific energy, flexible design and long life, lithium-ion batteries have become the first choice for electric vehicle power batteries with the improvement of their safety performance and cost reduction [1–5]. As a result, battery case materials have become more and more popular as an important part of square aluminum-shell lithium-ion batteries. However, the traditional aluminum alloy case materials cannot meet the demand for thinning of the battery cases in the future due to low strength or poor thermal stability [6, 7]. In order to solve this problem, this paper attempts to improve the mechanical properties and corrosion resistance by adding rare earth Ce.

Rare earth elements have important practical significance for the improvement and optimization of the microstructure and properties of alloys. In recent years, people have improved the various properties of aluminum alloys by adding rare earth elements such as Yb [8], Ce, La [9], Sm, Y, Nd, Gd, Er [10–13], and microalloying of aluminum alloys has been extensively studied. Subbiah et al [14] first added rare earth element Sc to aluminum alloys in 1971 to improve the strength of aluminum alloys. Xiao et al [15] added 0.25 ωt% of Ce to the Al-Cu-Mg-Ag alloy, and the yield strength of the alloy increased by 8.5% at room temperature, while the yield strength of the alloy increased by 85% at 350 °C. Chen et al [16] studied the effects of La and B elements on grain refinement and mechanical properties of cast Al-Si alloys. It was found that the addition of La and B elements formed LaB6 particles, which could significantly refine α-Al grains, so that the strength properties, particularly the elongation rate of the cast Al-Si alloy had been greatly improved. Du et al [17, 18] studied the effect of rare earth Ce on the as-cast microstructure and properties of aluminum alloy. The Al-Cu-Mn-Mg-Mn-Fe alloy with a small amount of Ce formed dense S′ phases after room temperature aging. Besides, during the deformation process, the aging precipitation S′ phases help to improve the mechanical properties of the alloy by
The equilibrium phase diagrams of the elements Al, Cu, Mn, Mg and Fe were calculated. It can be seen that the effect of the addition of rare earth Sm on the microstructure and corrosion properties of AZ292 magnesium alloy. It was found that in the process of solution-ageing, rare earth Sm could promote the precipitation of $\beta$-Mg$_{17}$Al$_{12}$ phase in the grains, inhibiting the precipitation of the phase on the grain boundaries, so that the $\beta$ phase became finer and the distribution was more uniform, which significantly reduced the macroscopic corrosion current between the phase and the substrate, so that the addition of an appropriate amount of rare earth Sm could improve the corrosion resistance of the alloy. Chen et al. [19] studied the effect of Ce on the microstructure and properties of Cu-Zn-Mn-alloys, and found that the addition of Ce significantly improved the electrochemical corrosion properties of the alloy. Based on the above-mentioned beneficial effects of rare earth elements on the alloy, we conclude that Ce may have the same improvement effect on the Al-Cu-Mn-Mg-Fe alloy.

In this paper, the appropriate amount of rare earth element Ce was added to Al-Cu-Mn-Mg-Fe alloy, which is used as the material of the lithium ion battery cases, to study the effects of Ce on the microstructure, mechanical properties and electrochemical corrosion properties of the alloy.

### 2. Materials and methods

The test raw materials were pure Mg, Al-Cu, Al-Mn, Al-Fe and Al-Ce intermediate alloys, which were smelted in a vacuum induction furnace to obtain an alloy ingot. The ingots were homogenized in a box-based resistance furnace and then air-cooled to room temperature. After the homogenization treatment, hot rolling was performed on a two-roll mill to obtain hot rolled sheet. The hot rolled sheet was then subjected to a stress relief annealing treatment in a box type electric resistance furnace. Cold rolling was performed on a two-roll mill to obtain a cold rolled sheet. After different placement times, the cold-rolled alloy sheet was subjected to a low-temperature annealing treatment at 150 °C for 24 h. The Ce in the sample is 0.254 wt%, and the actual composition of the alloy is shown in table 1.

The grain structure of the cross section of the rolled sheet along the vertical rolling direction was observed by a metallographic microscope (OM) under polarized light. The phase of the alloy was analyzed using an x-ray diffractometer (XRD, Rigaku D/ max 2500, CuKα, $\lambda = 1.54056$ Å). The transmission electron microscope and its accompanying energy spectrometer (Tecnai G2 F30 TEM) were used to analyze the microstructure and composition of the sample by means of images generated by transmission electron beam or diffraction electron beam. Scanning electron microscopy and its accompanying energy spectrometer (Quanta FEG 450 SEM) were used to observe the microstructure and composition of the sample, as well as the fracture morphology of tensile sample and the surface morphology of corroded sample.

The tensile test of the alloy was carried out in accordance with standard ASTM E8/E8M-13a. The fracture morphology of the tensile sample was observed using a secondary electron imaging mode of a scanning electron microscope. The aluminum alloy etching test was carried out according to the national standard (JB/T 7901–1999). The corrosion surface topography of the sample was observed using a backscatter mode of a scanning electron microscope. The Tafel measurement has a scan rate of 1 mV s$^{-1}$ and a scan range of $-1$ V to 0 V. The test was performed at room temperature (25 °C) with a mass fraction of 3.5% and 0.5% NaCl solution. The electrochemical impedance spectroscopy (EIS) test was performed using the same test apparatus as the Tafel measurement. The test temperature was room temperature (25 °C). Before the EIS test, the open-circuit potential-time curve of the sample was tested to determine its open circuit potential ($E_{corr}$). The initial potential of the test was $E_{corr}$ with an amplitude of 5 mV and a frequency of 100 KHz to 10 mHz.

### 3. Results and discussion

#### 3.1. Microstructure

Figure 1 is a graph showing the equilibrium phase content of Al-Cu-Mn-Mg-Fe alloy with nominal composition as a function of temperature by thermodynamic simulation using phase diagram calculation software JMatPro. The equilibrium phase diagrams of the elements Al, Cu, Mn, Mg and Fe were calculated. It can be seen that the

| Table 1. Nominal chemical composition of alloys (wt%). |
|-----------------|--------|--------|--------|--------|--------|--------|
| Alloy            | Cu     | Mn     | Mg     | Fe     | Ce     | Al     |
| Al-Cu-Mn-Mg-Fe  | 1.52   | 1.32   | 1.25   | 1.16   | 0      | el.    |
| Al-Cu-Mn-Mg-Fe-  | 1.48   | 1.33   | 1.21   | 1.21   | 0.254  | el.    |
| 0.254 Ce         |        |        |        |        |        |        |
Al₆Mn phases have the highest content among several intermetallic compounds in the stable state of the alloy. A certain amount of Fe has been added to the alloy, and it is foreseeable that the Al₆Mn particles in the actual alloy should exist in the form of Al₆(Mn, Fe) phases [20, 21]. When the temperature is lower than 395 °C, the S (Al₂CuMg) phase appears, and the content of the S phase and the Al₆Mn phase increases as the temperature decreases, and then tends to be stable. When the temperature is below 380 degrees C, the T (Al₂₀Cu₂Mn₃) phase decreases, the T (Al₂₀Cu₂Mn₃) phase disappears at less than 280 degrees C, and the Al₇Cu₂Fe phase disappears at less than 250 degrees C. In the equilibrium state, the calculated equilibrium microstructure of Al-Cu-Mn-Mg-Fe alloy at 300 °C mainly consists of alpha-al phase, Al₆Mn phase, S phase, T phase and Al₇Cu₂Fe phase. In the actual production process, the cooling speed is faster, which may be different from this.

Figure 2 shows topographical images of the polarized metallographic phase of the Al-Cu-Mn-Mg-Fe alloy in the vertical rolling direction after aging at room temperature before and after Ce addition. Due to the effect of rolling stress, the grains were stretched along the rolling direction, showing a finer fibrous tissue. According to figures 2(a) and (b), it can be found that when the magnification is the same, compared with the alloy without Ce, the grain size of the 0.254 wt% Ce alloy is much finer, indicating that rare earth Ce has a significant effect on the grain refinement. Due to the addition of Ce, a new rare earth-rich phase Al₈Cu₄Ce was formed. Al₈Cu₄Ce belongs to the tetragonal crystal system, and its lattice parameters are a = 0.8824 nm and c = 0.5158 nm. As an
intermetallic compound, \( \text{Al}_8\text{Cu}_4\text{Ce} \) has a relatively high melting point and will have a certain effect on the mechanical properties of Al-Cu-Mn-Mg-Fe \([22]\).

The phase composition of the Al-Cu-Mn-Mg-Fe alloy before and after the addition of Ce was analyzed by XRD, and the results were shown in figure 3. The main constituents of the alloy in which Ce is not added and added with 0.254 wt% Ce are \( \alpha \)-Al phase, \( \text{Al}_6\text{Mn} \) or \( \text{Al}_6(\text{Mn, Fe}) \) phase, \( \text{Al}_2\text{CuMg} \) phase and \( \text{Al}_7\text{Cu}_2\text{Fe} \) phase. Due to the addition of Ce, a new rare earth-rich phase \( \text{Al}_8\text{Cu}_4\text{Ce} \) is formed. Due to the large chemical affinity between Ce and Cu atoms, there is a strong interaction between Ce and Cu \([23, 24]\). Therefore, when Ce is added to the Cu-containing aluminum alloy, a rare earth-rich \( \text{Al}_8\text{Cu}_4\text{Ce} \) phase is formed. As a new forming phase, it will have a certain influence on the microstructure, mechanical properties and corrosion properties of Al-Cu-Mn-Mg-Fe alloy.

Figure 4 shows SEM images of the microstructure of Al-Cu-Mn-Mg-Fe alloy before and after the addition of Ce. It is found that different Mn/Fe ratios would affect the morphology of Fe-enriched intermetallic compounds, which in turn affect the mechanical properties of the alloy, consistent with the results of Shabestari and Malekan \([25]\). The coarse \( \text{AlMnFe} \) particles are broken into smaller irregular particles during deformation such as hot rolling and cold rolling. In alloys without Ce, the main intermetallic compounds are gray with irregularly shaped particles A, and the energy spectrum indicates that the intermetallic compounds are \( \text{Al}_6(\text{Mn, Fe}) \). After the addition of 0.254 wt% Ce, some irregularly shaped white intermetallic compounds B appear, and the energy spectrum indicates that such intermetallic compounds are \( \text{Al}_8\text{Cu}_4\text{Ce} \) \([26, 27]\). Comparing figures 4(a) and (b), it can be seen that the size of \( \text{Al}_6(\text{Mn, Fe}) \) intermetallic compound of the alloy is significantly reduced after adding 0.254 wt% Ce. According to figures 4(c) and (d), it can be seen that the diffraction peaks of the alloy after adding 0.254 wt% Ce are denser than those of the alloy without Ce, that is, the addition of Ce will increase the solid solubility of Mn in the aluminum matrix, thus refining the iron-rich phase \( \text{Al}_6(\text{Mn, Fe}) \) to some extent, which is consistent with the research results of Jiang et al \([28]\).

Figure 5 is a TEM morphology and measurement specification diagram of Al-Cu-Mn-Mg-Fe alloy before and after Ce is added. It can be seen that a large number of rod-shaped and disc-shaped intermetallic compounds are present in the alloy. The energy spectrum shows that the rod-shaped intermetallic compounds are \( \text{Al}_{20}\text{Cu}_2\text{Mn}_3 \) phases, the disc-shaped intermetallic compounds are \( \text{Al}_2\text{CuMg} \) (S) phases, and the intermetallic compounds A are \( \text{Al}_6(\text{Mn, Fe}) \) phases \([29]\). It can be seen from figures 5(a) and (b) that the alloy without Ce contains more S phases, the alloy with 0.254 wt% Ce contains more T phases. In addition, through the morphology of the T and S phases in the alloy before and after Ce addition, the addition of 0.254 wt% Ce refines the S and T phases of the alloy.

### 3.2. Mechanical properties

In order to study the fracture mechanism of the alloy, the fracture morphology of the alloy was observed by SEM. Figure 6 shows SEM images of the fracture surface of Al-Cu-Mn-Mg-Fe alloy before and after Ce addition. Some
larger micron-scale dimples can be found on the fracture surface, as well as submicron, nanoscale fine dimples that are smaller in size distributed between larger dimples. There are a large number of intermetallic compounds with large sizes in the alloy without Ce and the energy spectrum shows that these intermetallic compounds are $\text{Al}_6(\text{Mn, Fe})$, see figure 4(c). Similar to the study by Chai et al [30], large dimples are generally formed at the larger intermetallic compounds $\text{Al}_6(\text{Mn, Fe})$ and $\text{Al}_8\text{Cu}_4\text{Ce}$, while smaller dimples may be formed at smaller internal phases (e.g. T phases and and S phases). $\text{Al}_6(\text{Mn, Fe})$ is a brittle phase, which will significantly deteriorate the mechanical properties of the alloy when it is larger.

Table 2 shows the tensile mechanical properties of Al-Cu-Mn-Mg-Fe alloy before and after the addition of Ce at room temperature. It can be seen that the tensile strength, yield strength and elongation of the alloy after adding 0.254 wt% Ce have increased to some extent. Compared with the absence of Ce, the alloy with 0.254 wt% Ce increased the yield strength and tensile strength by 7% and 15%, respectively, and the elongation increased from 3.1% to 4.8%. It is shown that rare earth Ce can improve the comprehensive mechanical properties of Al-Cu-Mn-Mg-Fe alloy at room temperature. This is because the addition of a small amount of Ce significantly refines the $\text{Al}_6(\text{Mn, Fe})$ intermetallic compound and promotes the formation of more $\text{Al}_{20}\text{Cu}_3\text{Mn}_3$ phase, thereby significantly improving the overall mechanical properties of the alloy.

As mentioned above, Ce alloying can promote aging precipitation and S phase growth. Aging precipitates play an important role in enhancing the mechanical properties of Al-Cu-Mn-Mg-Fe alloys by preventing the movement of dislocations or defects. On the other hand, Ce alloying can significantly refine $\text{Al}_6(\text{Mn, Fe})$ precipitation.

3.3. Corrosion performance

In order to evaluate the effect of rare earth Ce on the corrosion resistance of Al-Cu-Mn-Mg-Fe alloy, we tested the Tafel measurement of the alloy before and after the addition of Ce at room temperature. The Tafel measurement of the Al-Cu-Mn-Mg-Fe alloy before and after the addition of Ce show the same morphology, which is the E-I behavior curve of typical aluminum alloy corrosion. The cathode branch is controlled by the hydrogen evolution reaction and exhibits a linear behavior, and the hydrogen evolution reaction process can be represented by the formula (1) [31]. The anode current density increases as the anode overpotential increases, indicating that the anode process is controlled by the activation process. In the $\text{Cl}^-$-containing solution, this anode process can be represented by the formulas (2) to (4).

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Figure 4. SEM images of the Al-Cu-Mn-Mg-Fe alloys with before and after adding Ce. (a) Ce-free, (b) 0.254 wt% Ce, (c) EDS pattern of the particle A (d) EDS pattern of the particle B.
Figure 5. TEM images of the Al-Cu-Mn-Mg-Fe alloys with before and after adding Ce. (a) Ce-free, (b) 0.254ωt% Ce, (c) EDS pattern of the S phase, (d) EDS pattern of the T phase.
Figure 7 shows the SEM surface morphology of the Al-Cu-Mn-Mg-Fe alloy before and after adding Ce through the Tafel measurement in different concentrations of NaCl solution at room temperature. It can be seen from the figure 7 that the corrosion morphology of Al-Cu-Mn-Mg-Fe alloys is quite different in the 3.5% NaCl solution and the 0.5% NaCl solution. After the Tafel measurement, a large concentration of NaCl solution form more corrosion convex hulls, and the convex hulls appear white. This is because the main component of the convex hull is non-conductive Al$_2$O$_3$. Under the irradiation of the electron beam, since there is no conductive path, the charge is concentrated on the surface of Al$_2$O$_3$ and appears white. Compared with the alloy without Ce, the alloy with 0.254 wt% Ce is significantly less in the amount of corrosion convex hull, which is consistent with the result that the corrosion current density of 0.254 wt% Ce alloy is significantly reduced. In Table 2. Tensile mechanical properties of Al-Cu-Mn-Mg-Fe Alloy before and after Adding Ce.

| Alloy                        | $\sigma_{0.2}$ (MPa) | $\sigma_b$ (MPa) | $\delta$ (%) |
|-----------------------------|----------------------|------------------|--------------|
| Al-Cu-Mn-Mg-Fe              | 240 ($\pm$4.1)       | 283 ($\pm$2.4)   | 3.1 ($\pm$0.2) |
| Al-Cu-Mn-Mg-Fe-0.254 wt% Ce| 256 ($\pm$3.6)       | 326 ($\pm$2.5)   | 4.8 ($\pm$0.2) |

Figure 7 shows the SEM surface morphology of the Al-Cu-Mn-Mg-Fe alloy before and after adding Ce through the Tafel measurement in different concentrations of NaCl solution at room temperature. It can be seen from the figure 7 that the corrosion morphology of Al-Cu-Mn-Mg-Fe alloys is quite different in the 3.5% NaCl solution and the 0.5% NaCl solution. After the Tafel measurement, a large concentration of NaCl solution form more corrosion convex hulls, and the convex hulls appear white. This is because the main component of the convex hull is non-conductive Al$_2$O$_3$. Under the irradiation of the electron beam, since there is no conductive path, the charge is concentrated on the surface of Al$_2$O$_3$ and appears white. Compared with the alloy without Ce, the alloy with 0.254 wt% Ce is significantly less in the amount of corrosion convex hull, which is consistent with the result that the corrosion current density of 0.254 wt% Ce alloy is significantly reduced. In
other words, in 3.5% NaCl solution, the alloy with appropriate amount of Ce can improve the corrosion performance of the alloy. In the 0.5% NaCl solution, the corrosion degree of the corrosion surface of the alloy is significantly lighter than that of the 3.5% NaCl solution, indicating that the NaCl content in the solution is an important factor affecting the corrosion performance of the alloy. The higher the NaCl concentration, the greater the corrosion degree of the alloy. Comparing figures 7(a), (c) with figures 7(b), (d), it can be found that, compared to 3.5% NaCl solution, rare earth Ce has little effect on the corrosive surface profile of the alloy in 0.5% NaCl solution, which is also consistent with the previous result that the alloy with rare earth Ce has little influence on the corrosion current density in 0.5% NaCl solution.

Figure 8 is a Tafel polarization curve of an Al-Cu-Mn-Mg-Fe alloy in a 0.5% NaCl solution and a 3.5% NaCl solution before and after Ce is added at room temperature. The polarization curves before and after the addition of Ce showed similar morphology, and both showed the activation control process of the cathode and anode.

Table 3 shows the corresponding electrochemical parameters calculated by the Tafel method. For alloys without Ce, the corrosion potential (Ecorr) shifts negatively and the corrosion current density (Icorr) increases with increasing NaCl solution concentration, indicating that the higher the NaCl concentration, the greater the corrosion degree of the alloy, which is consistent with the above observation results of SEM morphology. Compared with the alloy without Ce, the corrosion potential (Ecorr) is shifted while the corrosion current density (Icorr) is decreased in the same NaCl test solution. When the solution concentration increased from 0.5% to 3.5%, the corrosion current density (Icorr) without Ce alloy increased by 141.92%, and the corrosion current density (Icorr) with 0.254±4% Ce alloy increased by 56.75%. Therefore, compared with the alloy without Ce, the alloy with 0.254±4% Ce has better corrosion resistance, that is, the addition of rare earth Ce can improve the corrosion resistance of the alloy.

Figure 9 shows the electrochemical impedance spectroscopy of Al-Cu-Mn-Mg-Fe alloy after soaking in 0.5% NaCl solution for 1 h before and after adding Ce at room temperature. Figures 9(a) and (b) are Bode diagrams. The amplitude-frequency diagram 9 (a) shows a straight line with a slope of approximately −1, indicating that the impedance of the system is under the capacitive reactance control at this frequency range. Although the
phase frequency diagram (b) has only one extreme value, the phase angle peak at intermediate frequency is wide, indicating that the two time constants of the Al-Cu-Mn-Mg-Fe alloy overlap. Figure 9(c) is a Nyquist diagram composed of capacitive impedance arc and low-frequency diffusion impedance. A larger capacitive reactance radius represents a larger impedance, i.e. a greater electrochemical reaction resistance. Compared with the absence of Ce, the alloy with 0.254 wt% Ce has a larger impedance, indicating that the addition of rare earth Ce can optimize the corrosion resistance of the alloy.

Table 3. Potentiodynamic polarization curves parameters of the alloys tasted in 0.5% and 3.5% NaCl solutions.

| Alloy                             | Solution | $E_{corr}$ (mV versus SHE) | $I_{corr}$ ($\mu A \cdot cm^{-2}$) |
|----------------------------------|----------|-----------------------------|----------------------------------|
| Al-Cu-Mn-Mg-Fe                   | 0.5% NaCl| $-639(\pm5)$                | 6.25(±0.6)                       |
|                                  | 3.5% NaCl| $-686(\pm4)$                | 15.12(±0.7)                      |
| Al-Cu-Mn-Mg-Fe-0.254 wt% Ce     | 0.5% NaCl| $-622(\pm4)$                | 5.78(±0.5)                       |
|                                  | 3.5% NaCl| $-677(\pm5)$                | 9.06(±0.6)                       |
Figure 10 is an equivalent circuit diagram, and its resistance impedance results are also fitted based on these two circuit diagrams. The electrochemical parameters fitted according to the equivalent circuit are shown in Table 4. The solution resistance $R_s$ of the Al-Cu-Mn-Mg-Fe alloy does not change much before and after Ce is added, which indicates that the corrosion solution system is relatively stable. Compared to the Al-Cu-Mn-Mg-Fe alloy with 0.254\% Ce, the charge transfer resistance of the Al-Cu-Mn-Mg-Fe alloy without Ce is smaller, indicating that the charge transfer speed of the alloy is relatively fast, its corrosion resistance is poor, $W_p$ is smaller, the corrosion product is easier to diffuse, and the corresponding alloy is easier to corrode. Therefore, the corrosion resistance of Al-Cu-Mn-Mg-Fe alloy with 0.254\% Ce is stronger, which is consistent with the experimental impedance spectrum results.

Typically, the intermetallic compound and matrix in the alloy have different corrosion potentials. Therefore, when the alloy is placed in a corrosive environment, many corrosion galvanic couples are formed on the surface.
to accelerate the corrosion of the alloy. When the size of the intermetallic compound is large, it adversely affects the corrosion performance of the alloy. We have demonstrated that the microalloying of the Ce element significantly refines the \( \text{Al}_x(\text{Mn, Fe}) \) intermetallic compound. Therefore, Ce microalloying can improve the corrosion resistance of the alloy. On the other hand, Ce in the alloy during the etching process may dissolve and redeposit and concentrate on the surface of the alloy. This contributes to the formation of a continuous passivation film, weakening the influence of Cl\(^{-}\), thereby contributing to an improvement in corrosion resistance.

4. Conclusion

According to the experimental results, the following conclusions are drawn:

(1) For the low-temperature annealed Al-Cu-Mn-Mg-Fe alloy, XRD and phase diagram calculations show that the main phases in the alloy are \( \alpha \)-Al matrix, \( \text{Al}_x\text{Mn}/\text{Al}_x(\text{Mn, Fe}) \) phase, \( \text{T}(\text{Al}_{60}\text{Cu}_{23}\text{Mn}_{17}) \) phase, \( \text{S}(\text{Al}_x\text{CuMg}) \) phase, \( \text{Al}_x\text{Cu}_2\text{Fe} \) phase. A new rare earth phase \( \text{Al}_x\text{Cu}_4\text{Ce} \) appears in the Al-Cu-Mn-Mg-Fe alloy due to the addition of Ce.

(2) For the low-temperature annealed Al-Cu-Mn-Mg-Fe alloy, the tensile strength of alloys added with rare earth Ce increases. Compared with the Ce-free alloy, the yield strength and tensile strength of 0.254 wt% Ce microalloyed alloy increased by 7% and 15%, respectively, and the elongation increased from 3.1% to 4.8%. The rare earth Ce can be used to improve the comprehensive mechanical properties of Al-Cu-Mn-Mg-Fe alloy at room temperature.

(3) For the low-temperature annealed Al-Cu-Mn-Mg-Fe alloy, the Tafel measurement indicates that the corrosion potential of the addition of 0.254 wt% Ce alloy is positively shifted, and the corrosion current density is reduced, i.e., it has better corrosion resistance. Electrochemical impedance spectroscopy indicates that the addition of 0.254 wt% Ce alloy has a large corrosion resistance, indicating that the proper amount of rare earth Ce can improve the corrosion performance of Al-Cu-Mn-Mg-Fe alloy.

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