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Interdiffusion of Elements in Aluminum 2024 Clad During Reheat Treatment Process at 495°C

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Abstract. Aluminum alloy 2024 is normally strengthened with alloying elements of Cu and Mg. As these elements reduce the corrosion resistance of the materials, a pure Al clad is normally applied. Nevertheless, during ageing at high temperatures, inter-diffusion between elements can occur causing the recession of the clad. This study investigated the inter-diffusion behavior of Al 2024 clad at ageing temperature of 495°C and predicted the clad lifetime due to reheat treatment process. The depletion rate of clad was found at 0.8 μm per-hour of heat treatment. It is predicted that the thickness of the Al 2024 clad will no longer meet with the specifications on heat treatment for 42 hours at 495°C.

Introduction

Duralumin is a group of aluminum alloy containing about 4% copper which has higher mechanical strength when heat-treated compared than that of pure aluminum, and therefore, this material is widely used in aircraft industry [1]. However, the corrosion resistance of these materials is reduced. Therefore, commercial duralumin plate is normally covered with aluminum sheets on both surfaces to produce aluminum clad [2,3]. Nevertheless, the chemical composition difference between duralumin and the clad increase the chemical potentials. Consequently, when this alloy is heat-treated at high temperature, an inter-diffusion tendency between elements occurs in which Cu and Mg diffuse into the clad, while aluminum diffuses into the substrate [4]. This causes clad depletion phenomenon that reduces clad life time. In case of heat treatment process, the phenomenon of depletion tendency should be considered to find out the limitation of reheat treatment cycles that allowed in practice.

The depletion of aluminum clad during heat treatment process of aluminium alloys has not been intensively studied [5]. This depletion tendency is basically controlled by interdiffusion mechanism. Nowadays, diffusion of the ternary Al–Cu–Mg system has been well developed through an experimental method [6] such as the CALPHAD method [7]. However, the diffusion data have not been accomodated to evaluate the depletion of Al2024 clad when heated during heat treatment process. The clad depletion was predicted because of displacement of $\alpha/\alpha+\theta$ interface layer to the outer surface side. The displacement of $\alpha/\alpha+\theta$ interface was proposed comply to the following equation.

$$(C_i^{\alpha} - C_i^{\alpha+\phi})\frac{d\xi}{dt} = \tilde{J}_{i,\xi}^{\alpha} \tag{1}$$

in which C_i^{α} and $C_i^{\alpha+\phi}$ respectively are the equilibrium concentrations of elements in the α clad and α+θ at interface, $\frac{d\xi}{dt}$ is the α/α+θ interface velocity, i is Cu and/or Mg, and $\tilde{J}^{\alpha}_{i,\xi}$ is the inter-diffusion flux of elements in α phase next to the α/α+θ interface.

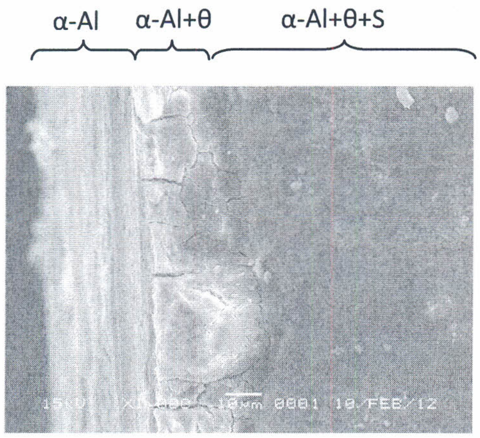
The clad depletion can be predicted from the α/α+θ interface movement through the following general diffusion control equation, $\xi = \alpha\sqrt{t}$, where α is rate constant and t is time. The rate constant α was analytically calculated by Nesbitt and Heckel [8] for ternary alloys of Ni-Cr-Al based on previous studies by Kirkaldy [9.10] on motion of planar phase interfaces in multi component systems. This study aims to predict the life time of the Al 2024 clad by considering the diffusions of Cu and Mg in the clad of α-Al that influence the movement of α/α+θ interface. Ternary system of Al-Cu-Mg was selected as the alloy model, as the other elements present in Al 2024 are minor. The equilibrium concentration of Cu and Mg in α and α+θ at α/α+θ interface were selected based on the chemical analysis of the samples with refer to the ternary phase diagram of Al-Cu-Mg at 495°C. The rate constant α was obtained analytically and verified with the experimental result.

Experimental Procedures

Al 2024 clad samples were cut from bulk samples in the size of 16 mm x 16 mm having total thickness of 2.38 mm, including clad thickness of 55 microns on both surface sides. The average nominal chemical composition of the 2024 material is 96.5Al-2.1Cu-1.4Mg (all compositions are in wt.%). Re-heat treatment was simulated by heating the 2024 Al clad at 495°C in argon gas tube furnace for 1 hour followed by rapid cooling to room temperature and then ageing at 190°C for 10 hours. This was counted as one cycle of heat treatment. The simulation experiment was done until 6 cycles. All sample were then prepared using standard metallographic techniques. The polished and etched cross-sections were analyzed using optical microscopy and scanning electron microscopy (SEM) where energy dispersive x-ray analysis (EDAX) device is attached. The concentration profiles across the clad samples were identified and found on the basis of EDAX results. The coating and substrate boundaries were confirmed mainly from EDAX results.

Results and Discussion

The representative microstructure of the Al 2024 clad together with a corresponding concentration profiles for the sample re-heat treated at 6 cycles is shown in Fig. 1 and Fig. 2, respectively. The minimum thickness of the clad that still be accepted is 1.5% of the total thickness, in which it is equal 24 μm. Figure 3 shows the relation between clad recession and time from which the rate constant α of 4.6×10^{-7} m.sec$^{1/2}$ is obtained. The time of reheat treatment for the clad to have a minimum thickness of 24 μm is found at 42 hours and this provides available reheat treatment process for 42 cycles. Nevertheless, it should be noted that other microstructural changes, such as particle coarsening in the substarte, can also occur that affects the mechanical properties of the whole materials. Further investigation on this matter is required to provide complete information especially for aircraft industries concerns.



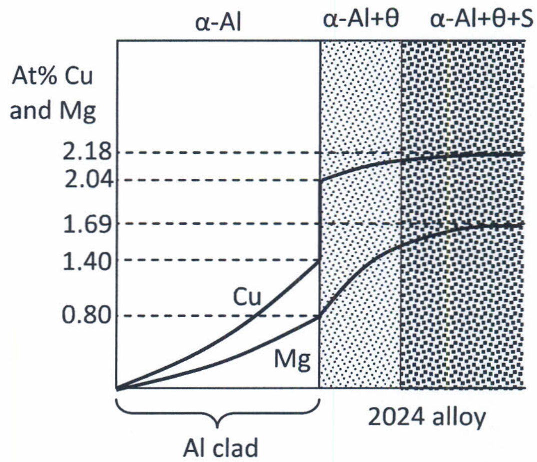


Figure.1. Microstructure of Al clad 2024 after reheat treatment for 6 cycles.

Figure.2. Concentration profiles of Fig.1

It is found in this study that the concentrations of elements in α and α+θ phases at the interface of α/α+θ for all cycles were basically constant indicated by point (b) in Figure 4. Therefore, the diffusion path during reheat treatment of Al 2024 clad at 495°C was proposed as indicated by dot line of a-b-c-d. It is defined that (a) is the original Al clad composition, while (d) is composition of the 2024 alloy substrate. These compositions were used to predict the rate constant α using analytical model proposed by Nesbitt and Heckel [8]. The ternary diffusion coefficients data used in this analytical model, *i.e.*, $D^{Al}_{Cu,Cu} = 9.0\text{x}10^{-13}$, $D^{Al}_{Mg,Mg} = 1.8\text{x}10^{-12}$, $D^{Al}_{Cu,Mg} = 2.34\text{x}10^{-13}$, and $D^{Al}_{Mg,Cu} = 2.16\text{x}10^{-13}$, were adopted from the previous work of Takahashi, et.al [11]. The simulation of the analytical model provides α equal with $1.14\text{x}10^{-6}$ m.sec$^{-1/2}$, which is about 2.5 times higher than that found in the experiment. Trace elements in the alloy and ageing treatment were predicted responsible for this different.

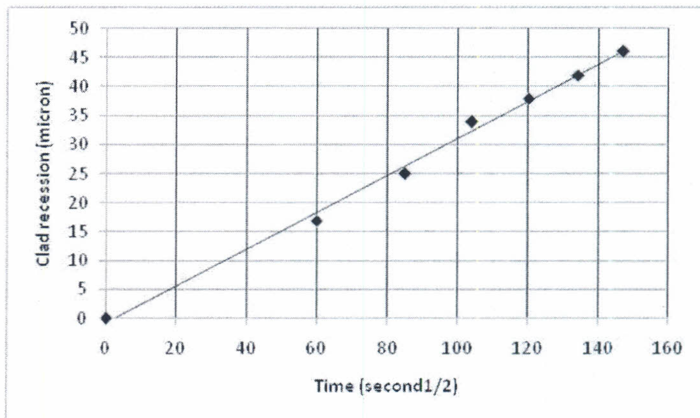


Figure.3. Clad depletion vs reheat treatment time

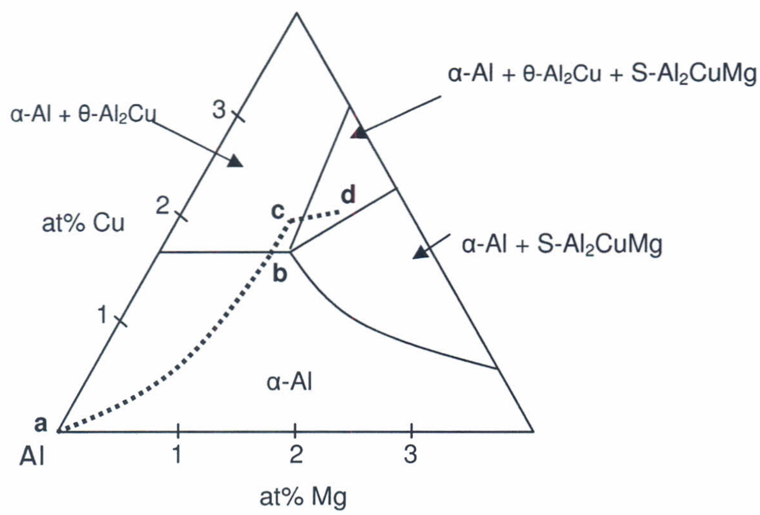


Figure.4. Diffusion path during reheat treatment of Al 2024 clad at 495°C.

Conclusion

The study of clad depletion phenomenon of Al 2024 clad during reheat treatment revealed that Cu and Mg diffuse from the Al 2024 substrate into the pure Al clad on the surface side. Al diffuses inwardly causing the depletion of the clad, indicated by α/α+θ interface layer shifts outwardly. The initial clad thickness of 52 μm tends to deplete to reach a minimum thickness of 24 μm winthin 42 hours. An analytical analysis was used to predict the kinetics of this interface and found a constant of depletion rate slightly different.

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