CREEP AGE FORMING OF Al-Zn-Mg ALLOYS WITH OPTIMIZATION OF MECHANICAL PROPERTIES

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Abstract: *Creep age forming (CAF) is one of the novel methods in aerospace industry that has been used to manufacture components of panels with improved mechanical properties and reduced fabrication cost. CAF is a combined age-hardening and stress-relaxation that are responsible for strengthening and forming, respectively. This paper deals with the experimental investigations of mechanical and springback properties of Al-Zn-Mg Al alloy in creep forming process. Creep forming experiments have been performed at temperatures of 120 °C and 180 °C for 6–72 h. Results indicated that yield stress and hardness of creep age formed specimens increased with increasing forming time and temperature, simultaneously induced deflection by stress-relaxation increased. Incorporating spring back and mechanical properties, it can be found that the appropriate forming cycle was 180 °C/24 h among all forming conditions. CAF Time increase to a certain extent increased mechanical properties. This can be attributed to presence of stress in CAF that causes the precipitates be finer because of creation more nucleation sites. Therefor the growth of precipitates, takes place at long time and postpones the decreasing of the yield stress.*

Keywords: *Creep Age Forming, Al-Zn-Mg Alloy, Age Hardening, Stress Relaxation, Mechanical Properties*

1. INTRODUCTION

Creep age forming is useful for forming accuracy and excellent mechanical properties since it combines mechanical forming and age-hardening, and age-forming has been successfully used to manufacture airplane upper wing skins for a number of years. For example, Textron formed the upper wing skins of the Gulfstream GIV, B-1B long range combat aircraft and Airbus A330/340, and lately Bennetts Associate worked with Airbus on creep forming the wing skin for the latest A380 [1–4]. CAF as a novel process, that involves simultaneous forming and artificial ageing, is currently applied to production of aerospace metal structures [2, 3]. CAF consists of elastic loading an aluminium panel onto a tool surface using vacuum bagging technique (loading phase). Once in full contact with the tool surface, the panel is held at a specific temperature for a controlled amount of time. During thermal exposure (creep-ageing phase), the constituents of the material precipitate and alter the material microstructure. At the same time, stress relaxation occurs due to creep and introduces some permanent deformation in the material. Finally, the panel is released and springs back to a shape somewhere between its original shape and the tool shape (unloading phase). Springback occurs due to the elastic recovery of the stresses. According to the nature of components formed by CAF, the boundaries of the panel are not clamped and the deformation is close to pure bending, which generates low plastic strains in the formed part [4]. the main advantages of creep forming are the accuracy and repeatability that can be achieved as well as the ability to produce panel components with multiple curvatures. On the other hand creep forming components have lower residual stresses. This improves the service performance of the part since it improves the resistance to both fatigue and stress corrosion cracking[5]. In the past two decades, several studies have been carried out on creep forming of aluminum alloys. They have mostly studied the creep forming behaviors of Al-Cu based alloys[6, 7]. However, there is limited information on the creep forming of Al-Zn based alloys in the literature. The aim of this study is to determine the suitable forming time and temperature during creep forming of

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Al-Zn-Mg alloy to attain optimum mechanical properties with concern of minimum spring back.

2. EXPERIMENTAL

2. 1. CAF Apparatus

In order to attain the precise value of spring-back in the CAF process and better control the variables, the CAF apparatus was designed and manufactured based on pure bending theory and elastic loading by vacuum bagging. This apparatus comprises a curved tool, heating equipment, heating chamber and vacuum bagging equipment. As shown in Fig.1a the curved tool is in a cylindrical form with constant radius of 0.5452 m along the x direction which leads to a maximum displacement of 30 mm in direction of z axis. This curved tool is embedded in heating chamber (Fig .1b). Fig.1c shows the whole assembly of CAF setup.

2. 2. Materials

The material was used in this study was 7075-Alcalad aluminum alloy with 3.2 mm thick. Chemical composition of as-received material is given in table 1.

Specimens dimensions of 350 mm×100 mm×3.2 mm were cut form a Al-Zn-Mg aluminum alloy sheet. Before CAF process, the specimens were solution treated at 480°C for 50 minutes and immediately water quenched to room temperature.

2. 3. CAF Test

CAF process was performed with the following sequence:

- The plate is first elastically loaded onto a tool surface by vacuum traction force, which varies from zero to a required pressure. Vacuum bagging performs by sealing the specimen on the tools and traction force that induced by vacuum pump sticks the plate on the tool surface.
- Once the plate contacts the tool surface completely, the CAF process begins with closing the chamber's door and thermal exposure of specimen in certain times and temperature.
- At the end of the creep-ageing time, the specimen is retrieved and specimen cooled at open atmosphere to air.

The forming temperature is determined according to the metallurgical properties required for the material. For 7xxx alloys ageing temperature is typically between 120 °C and 190 °C. In the case of aluminum alloys, creep temperatures lie between 0.4–0.5 Tm, where Tm is the melting point of aluminum [3]. Therefore, to obtain a good combination of mechanical properties and low level of springback, the ageing treatments were conducted at 120 °C and 180 °C for 6–72h.

2. 4. Spring Back Modeling and Final Deflection

For elastic loading, the relationship between the bending moments and the curvatures can be expressed as:

$$M_{11}^{0} = D(k_{11}^{0}), M_{11}^{f} = D\left(k_{11}^{f}\right) \tag{1}$$

where D is the flexural rigidity of the plate given by $D = \frac{Eh^3}{12(1-v^2)}$, E is Young's modulus, v is Poisson's Ratio and h is the thickness of the plate.

The deflection at the center of the plate can be calculated with the formula:

$$\delta^{0} = \frac{M_{11}^{0}}{2D(1-v^2)}\left(\frac{L}{2}\right)^2 \tag{2}$$

where L is the length of the plate. From the value of the final bending moments, the deflection of the plate after the tool is retrieved can be calculated as

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$$\delta^f = \delta^0 - \frac{M_{11}^f}{2D(1-\upsilon^2)}\left(\frac{L}{2}\right)^2 \quad (3)$$

The spring back is defined as the relative diminution of the deflection at the center of the plate before and after the tool is retrieved:

$$\text{Spring Back}(\%) = 100\left(1 - \frac{\delta^f}{\delta^0}\right) \quad (4)$$

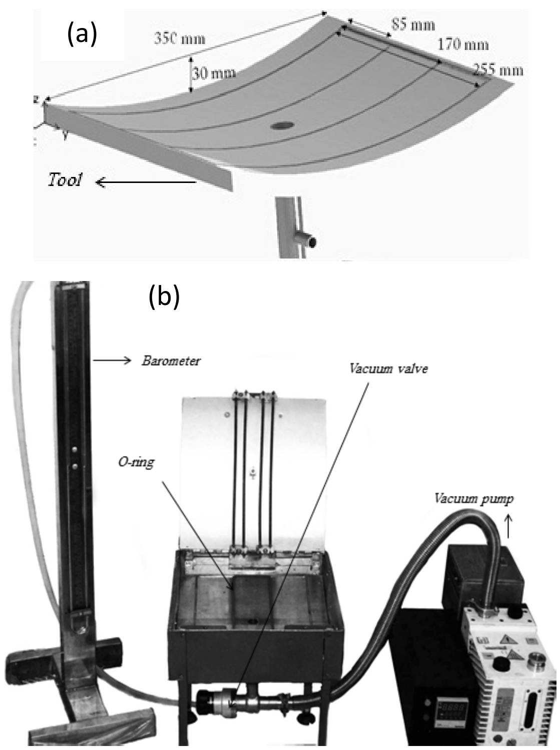

Fig. 1. (a) Schematic illustration of the tool surface. (b) Whole assembly of creep age forming apparatus.

Table 1. Chemical composition of Al-Zn-Mg aluminum alloy

Al	Zn	Mg	Cu	Fe	Si	Cr	Other
Bal.	5.20	1.95	1.22	0.25	0.23	0.17	0.08

2. 5. Hardness and Tensile Testing

Tensile tests in the perpendicular of rolling direction were performed at room temperature using an INSTRON 5500 machine operating at a constant crosshead speed of 5 mm/min. The stress strain curves were used to determine UTS and yield (0.2% offset) points. The Brinell hardness measurement was carried out with a $\frac{F}{d^2} = 5$ ratio.

3. RESULTS AND DISCUSSION

3. 1. Effect of CAF Time and Temperature on Momentum and Spring Back

Fig. 2 shows the evolution of the bending moment along x- and y-axes throughout the CAF process. The bending moment reaches its maximum value at the end of the first stage and drops quickly at the beginning of the ageing stage (stress relaxation is important).

Fig. 3 illustrates the spring back of creep age formed specimens under various forming condition. As can be seen in this figure, increasing of time and temperature of CAF process decline the value of sprig back. It is

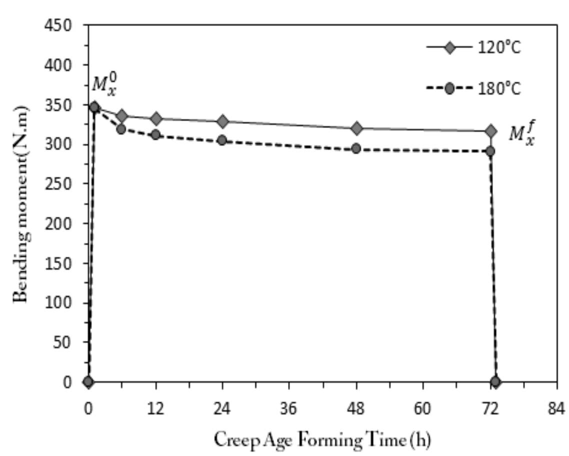

Fig. 2. Bending moment and curvature variations in a CAF process at difference temperature.

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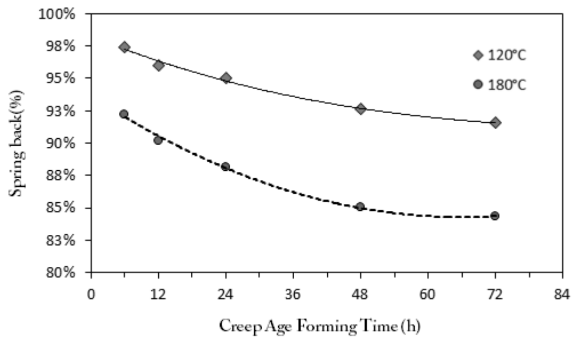

Fig. 3. Variations of spring back with forming time and temperature.

shown that at the high temperatures and longtime more stress relaxation was occurred[8]. It can be concluded that a CAF time of 48 h is sufficient because the value of springback reaches a stationary value.

3. 2. Effect of CAF Time and Temperature on Mechanical Properties

In CAF process, heat treatment cycles are dictated by optimum mechanical properties and geometry of the tool that restrict the optimization region for spring-back. In this way, mechanical properties of creep age formed specimens are plotted in Fig. 4. According to Fig. 4a yield stress in both temperatures increases first and then reaches a constant value. The change of strength can be attributed to the age-hardening due to the formation of solute clusters and subsequent precipitation and strain hardening due to the creep deformation [7-8]. Comparison of tensile stress shows that the yield stress at 180 °C at least state 60 Mpa higher than that at 120 °C. As can be seen from Fig. 4a the CAF time to reach peak strength decreases with increasing the CAF temperature. At 120 °C the yield stress after 48 hour reaches to its maximum value but at 180 °C that after 24 hour. After these times yield stress begin to decrease slightly. This can be attributed to presence of stress in CAF that causes the precipitates be finer because of creation more nucleation sites. Therefor the growth of precipitates, takes place at long time

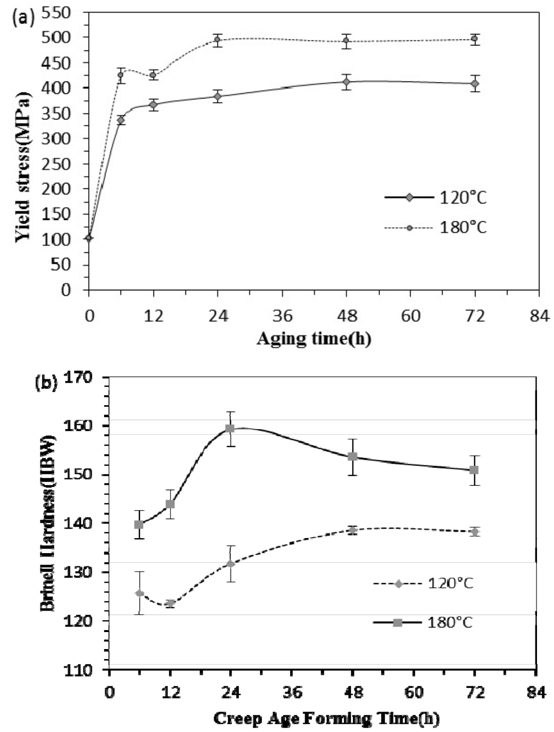

Fig. 4. (a) Variations of yield stress and (b) hardness at different temperature during the time.

and postpones the decreasing of the yield stress. The variation of hardness versus CAF time is shown in Fig. 4b. It is noticed that at both temperatures the hardness increases to a peak value and then decreases gradually. This is attributed to the over-ageing caused by the precipitation of coarse equilibrium phases after the optimum ageing time [7-8].

3. 3. Effect of CAF Time and Temperature on Microstructure

For better understanding it is worth mentioning the precipitation sequence in the 7xxx aluminum alloys examined by several investigators [10–11] as:

Supersaturatedsolidsolution → Guinier–Prestonzones → η→ ή ($MgZn_2$)

where ή is the metastable precipitate and η is the equilibrium $MgZn_2$ precipitate. The peak-strength condition is associated with a fine distribution of ή precipitates. After prolonged forming time, over-ageing phenomenon occurs, contributing to the coarsening of precipitated particles. Meanwhile, the precipitates will transform from semi-coherent (ή) to non-coherent (η). The stress required to move a dislocation around a particle is given by the expression [12]:

$$T=2Gb/\lambda \tag{5}$$

where G is the shear modulus, b is the Burger's vector and λ is precipitates spacing. During coarsening, the number of precipitates decreases and precipitates spacing increases further. Thus, according to Eq. (4), a lower stress is required for dislocation motion. Hence the effect of precipitates to pin dislocations and crystal boundaries to enhance the creep resistance of the alloy is reduced somewhat [13]. This is in good agreement with experimental results. As could be seen in Fig. 5 the microstructure of samples included highly elongated grain structures, so it can be suggested that diffusional creep mechanisms such as Nabarro–Herring and Coble creep, which are strongly dependent on grain size, are less likely to contribute significantly to the overall creep rates [14].

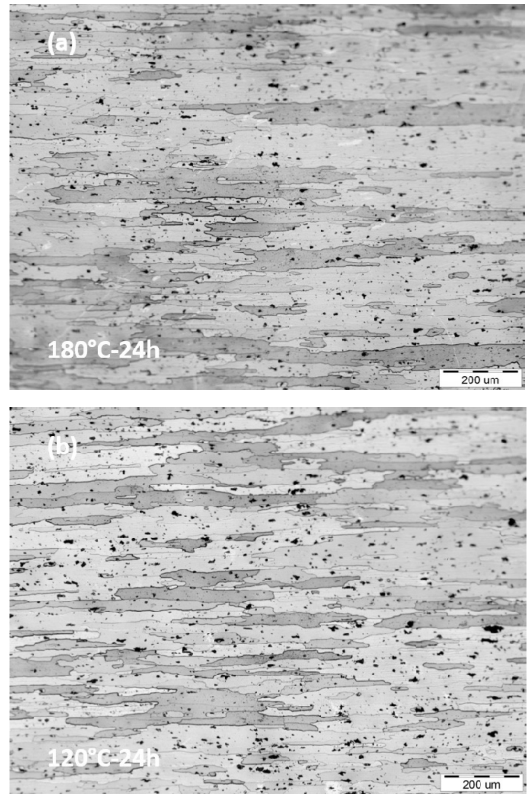

Fig. 5. optical micrographs showing the grains structure of samples, (a) 180 °C and (b) 120 °C.

4. CONCLUSION

- The springback decreased with increasing forming time and temperature due to increase of stress relaxation.
- Regarding springback and mechanical properties, appropriate properties were obtained at 180 °C/24h.
- Increas the CAF temperature Resulting in better mechanical properties.
- CAF Time increase to a certain extent increased mechanical properties.

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