



Effect of pre-deformation on creep age forming of AA2219 plate: Springback, microstructures and mechanical properties



Youliang Yang^{a,b,c}, Lihua Zhan^{a,b,c,*}, Qiangqiang Ma^{a,b,c}, Jingwen Feng^{a,b,c}, Xianmeng Li^{a,b,c}

^a State Key Laboratory of High-Performance Complex Manufacturing, Central South University, Changsha 410083, China

^b School of Mechanical and Electrical Engineering, Central South University, Changsha 410083, China

^c Collaborative Innovation Center of Advanced Nonferrous Structural Materials and Manufacturing, Central South University, Changsha 410083, China

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ABSTRACT

Applying pre-deformation to high strength aluminum alloy between solution treatment and artificial aging is one of the effective ways to relieve quench-induced internal stress and achieve improved mechanical properties. This paper studies the effects of pre-deformation on springback, microstructures and mechanical properties of creep-age formed 2219 aluminum alloy plate. The results show that the introduction of pre-deformation can remarkably reduce the amount of springback, enabling the radius of deformed plate gets closer to the target value (1160 mm). The radius and springback of pre-stretched plate after creep age forming are 1370.1 mm and 15.3%; while for non-stretched plate, the values are 1635.6 mm and 29.1%, respectively. Furthermore, the mechanical performances of pre-deformation plate are better than those of non-deformation plate and more evenly distributed. As compared with non-stretched plate, the pre-stretched plate has higher tensile strength by 7.3%, higher yield strength by 20.8% and much lower in-plane anisotropy (IPA) of properties. These differences are attributed to the combined effects of heterogeneous nucleation and growth of precipitates at dislocations, discontinuous precipitates and narrower precipitation free zone (PFZ) along grain boundaries together with unobvious stress orientation effect in the pre-stretched plate.

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1. Introduction

Creep age forming (CAF) is a new sheet metal forming technology, which consists of creep/stress relaxation and age hardening. This technology is suitable for fabricating large-contoured aircraft wing skins and rocket integral panels with ribs. Successful applications of CAF reported by Ho et al. (2004a) include the upper wing skins of the Gulfstream GIV, B-1B long range combat aircraft and Airbus A330/340/380. The description of CAF process can be simply summarized as: the workpiece to be formed is first pressed by mechanical clamping or vacuum bagging to fully contact with the tool surface, and is then held at a certain temperature for a controlled amount of time in the autoclave; last it springs back to a shape somewhere between its original shape and die surface after unloading. In this process, on one hand the elastic strain is partly converted to permanent plastic strain, thus the workpiece

accomplishes the desired configuration; on the other hand, due to the material microstructures optimization, the workpiece possesses good service performances of enhanced mechanical properties, reduced residual stress and increased resistance to stress corrosion cracking. However, the workpiece definitely springs back after unloading. This is due to the limitations on the maximum usable temperature and the forming time dictated by microstructure requirements. Hence, how to reduce the amount of springback and simultaneously obtain sound mechanical properties of creep-age formed workpiece is the key problem required to solve for the widespread application of CAF technology.

Extensive investigations on springback and mechanical performances of creep-age formed part have been made over the years. Zhan et al. (2013a) revealed that the amount of springback in CAF process decreases almost linearly with increase in aging time and temperature, but increases with increasing bending radius in linear springback-Log bending radius scale. Wang et al. (2013) claimed that springback tends to decrease nonlinearly with increase of part thickness. By means of orthogonal test and extreme difference analysis of experimental results, Zhan et al. (2012) pointed out the weight sequence of four main process parameters in CAF

* Corresponding author at: State Key Laboratory of High-Performance Complex Manufacturing, Central South University, Changsha 410083, China.

E-mail address: yjs-cast@csu.edu.cn (L. Zhan).

process on springback in accordance with the following order: aging temperature, holding time, part thickness, and bending radius. Li et al. (2012) studied the creep age forming of workpiece welded by friction stir welding (FSW), and indicated that, as compared to integrally milled workpiece, the springback amount of FSWed workpiece increases, but the properties decrease. For panels with complicated ribs, Jia et al. (2013) and Zhan et al. (2013b) found that their springback values are reduced considerably due to the elastic recovery of skin restricted by the plastic strains of ribs. With respect to the effect of stress gradient along the plate thickness, Zhan et al. (2014) discovered that springback value increases with the decrease in stress gradient while maintaining the ratio of bending radius to plate thickness (R/H) unchanged and the compression side of the plate has higher mechanical properties as compared to tension side. Lv and Gang (2011) presented that integral panel's structures including rib height, convex platform height and deep grooves have critical influences on springback value. Jeshvaghani et al. (2012) found that the two-step heat treatment is not favorable, because the tensile properties decline significantly although springback decreases slightly. Inforzato et al. (2012) observed that the springback of 7475 aluminum alloy lower wing skin is strongly dependent on the stiffness and moment of inertia of each section, being higher as higher the stiffness. Zhang et al. (2013) demonstrated that springback is obviously influenced by the aging condition, and also related to the internal stress state of material. And the springback value of the plate specimens would be the minimum if the two factors reach the optimal coupling state. Moreover, plate with double-curvature has less springback and higher properties as compared to single-curvature plate. Ho et al. (2004b) used a set of creep damage constitutive equations for CAF springback simulation. The results indicated that creep mainly took place near the top and bottom surface of the workpiece and the amount of springback can be assessed by the ratio of "significant creep region" (SCR) and "less creep region" (LCR). Jeunechamps et al. (2006) concluded that the amount of springback in CAF decreases almost linearly as the curvature of the workpiece varies from single curvature to double curvature. Nevertheless, there is few studies concerning the influences of pre-deformation before CAF process on springback and mechanical properties of creep-age formed workpiece. Applying pre-deformation to high strength aluminum alloy is one of the vital ways to gain improved mechanical performances. Thus it is meaningful to investigate the effects of pre-deformation induced before CAF process on springback and mechanical properties of workpiece.

2219 aluminum alloy (AA2219), one of Al–Cu–Mn alloys, is precipitation hardening alloy through appropriate heat treatment. It is widely used in aerospace rocket integral panel components and aircraft skin structures due to the good combination of high strength and fracture toughness, good weldability and elevated temperature and cryogenic properties (Yin et al., 2014 and Wan et al., 2014). Using AA2219 as experimental materials, this paper investigates the effects of pre-deformation on springback, microstructures and mechanical properties of plate in the CAF process. Furthermore, the differences in springback, microstructures and mechanical properties between non- and pre-stretched plates are compared and analyzed in detail.

2. Experimental

The raw materials, AA2219, were provided by a company as the hot-rolled plates with the thickness of 10 mm. The exact chemical composition of AA2219 is given in Table 1. Two rectangular plates of 320 mm × 220 mm × 10 mm were machined out from the rolling direction of the as-received plate. Then two plates were synchronically subjected to solution treatment in the electrical resistance

Table 1

Chemical compositions of 2219 aluminum alloy (mass fraction, %).

5.24	0.028	0.27	0.042	0.13	0.03	0.14	0.065	Bal.
Cu	Mg	Mn	Si	Fe	Ni	Zr	Ti	Al

furnace for 60 min at 535 °C, followed by water quenching at ambient temperature. For the purpose of comparison, one plate was stretched along the rolling direction with the amount of 7% after solution treatment.

Creep age forming tests were carried out in a laboratory autoclave manufactured by Dalian Sakura Da Machinery Manufacturing Co., Ltd. Hot air passes through the air duct and flows into the working area to heat the workpiece (see Fig. 1); the temperature and pressure in the autoclave are controlled by PID system with the accuracy of ±1.5 °C and ±0.01 MPa.

The experimental procedure is described as follows: first, the plate was placed on the mould with the single curvature radius of 1160 mm and was forced to completely contact with the circular surface of the mould by a pressure of 5 atm which was calculated to be large enough to bend the plate; then, the assembly was creep-aged in the autoclave at 165 °C for 12 h; last, the plate was spring-backed after the pressure was released. Experiments were repeated on two pre-stretched and two non-stretched plates. The schematic diagram of creep age forming process is depicted in Fig. 2.

The radii of deformed plates were measured by the Atos raster scanner. Tensile tests were carried out at room temperature using an INSTRON 5500 machine operating at a constant speed of 2 mm/min. Microstructure observations were performed with a Transmission Electron Microscope (TEM). TEM slice samples were first machined down to 80 μm in thickness, followed by standard twin-jet electropolishing using 70% methanol and 30% nitric acid solution at –35 to –25 °C cooled by liquid nitrogen and lastly by anhydrous alcohol cleaning for 2 min after being punched into circular slices of 3 mm radius. In the end, TEM samples were observed by a JEOL-2010 Transmission Electron Microscope operating at 200 kV.

3. Results and discussion

3.1. Effect of pre-deformation on springback

The magnitude of plate's springback is quantitatively represented by:

$$SP = \left(\frac{1 - R_0}{R_f} \right) \times 100\% \quad (1)$$

where SP denotes the amount of springback, and the smaller the SP value is, the more accurate the configuration of deformed plate is; R_0 and R_f refer to the bending radius of the plate before and after the load is removed. Fig. 3 shows the schematic diagram for springback definition.

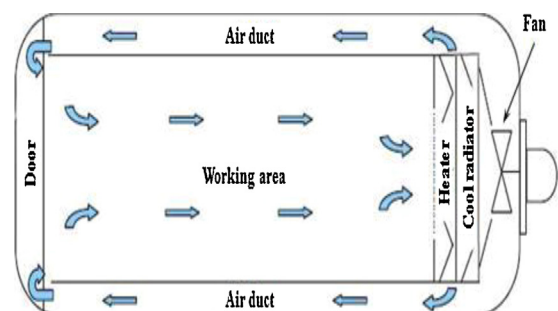


Fig. 1. Working principle diagram of the autoclave.

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