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Age Forming Technology for Aircraft Wing Skin

Takafumi Adachi, Shirou Kimura, Takahiro Nagayama,
Hiroyuki Takehisa, and Masakazu Shimanuki

Fuji Heavy Industries Ltd. Aerospace Company, 1-1-11,Yonan, Utsunomiya, Tochigi, 320-8564, Japan

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Abstract

The age forming process, in which the forming and aging of aluminum alloys can be accomplished simultaneously through their creep deformation, is well known as a low cost process for forming aircraft wing skins. On the other hand, integral wing skin structures are used for small aircrafts such as business jets, in order to reduce their weight and manufacturing cost. This paper presents a study on the possibility of applying the age forming process to double curvature integral wing skins and the feasibility of predicting the amount of springback after age forming.

1. Introduction

In recent years, requests from commercial aircraft customers are shifting toward low manufacturing cost as well as high performance. Age forming is one of the cost-effective processes for forming skins of parts such as the wings and fuselages of business jets. It utilizes creep deformation of an aluminum alloy during its heat treatment as illustrated in Figure 1 [1]. In this process, a structural piece is placed on a tool Figure 1 (1), pressed against the tool by vacuum bagging Figure 1 (2), and heated under pressure in an autoclave. After aging, the piece is cooled down and released Figure 1 (3). Springback that occurs because of residual strain at the time of release has to be taken into account in determining the process parameters and tooling so that the final configuration of the piece conforms to the drawing. The problem of this process is that springback in age forming is 40–70% larger than that obtained in typical cold working conditions, which makes it difficult to predict the exact amount of springback for double curvature and variable thickness designs. Therefore, the age forming process requires a number of tool trials and alterations until the contour of a skin piece conforms to the drawing, which increases their manufacture cost [2].

The purpose of the present study is to investigate the possibility of applying age forming to double curvature skins with variable thickness and establish a method to predict the amount of springback in order to reduce the manufacturing cost and weight of aircraft wings.

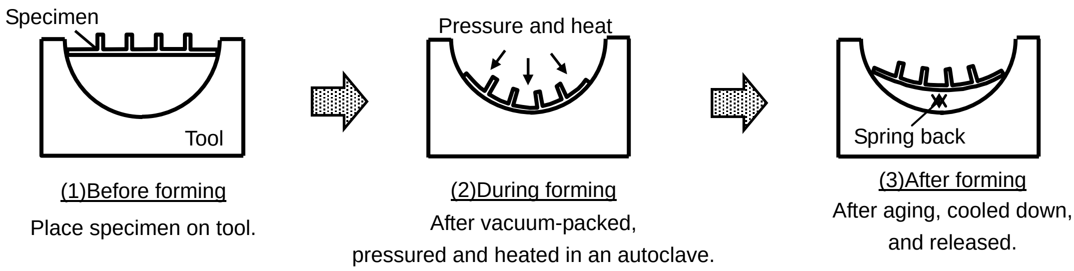

Figure 1: Age forming process.

2. Background of Age Forming Study

Typically, an aircraft wing structure is made first by shaping the stringers and skin separately and subsequently assembling them. A structure built in this manner is called a built-up structure. As illustrated in Figure 2(a), separately formed individual pieces have to be riveted together and sealed. One way to reduce the manufacturing cost and weight of an aircraft wing structure is to assemble the entire structure as illustrated in Figure 2(b). In this integral structure, the stringers are machined out of a thick plate. It is an effective way to reduce the weight and man-hours with an additional advantage of being less prone to fuel leakage in comparison with riveted and sealed structure.

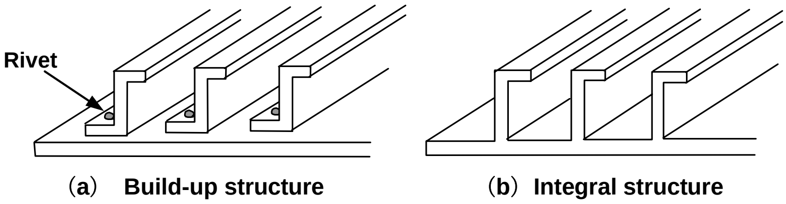

Figure 2: Integral structure and built-up structure.

Another way to reduce weight is to use high performance materials for wing structures. A recent trend followed in aircraft designing places great emphasis on the damage tolerance of aircraft structures even for small aircrafts. For such design materials possessing balanced properties are required which possess not only high static strength but also high fracture toughness. For the present study, 7475-T7351 aluminum alloy was selected, because it excels in fracture toughness and stress corrosion cracking (SCC) resistance. Further, as shown in Table 1, its static strength is higher than that of 7075-T7351.

Table 1: Properties of age formable material.

Material	Static strength [3]		Fracture toughness [4]		Stress corrosion cracking resistance (ST direction) [3]
	Tensile (MPa)	Yield (MPa)	K_{Ic}(MPa$\sqrt{m}$)	K_c(MPa$\sqrt{m}$)	
2024-T851	455	386	23	71	B
2124-T851	455	393	29	75	B
7075-T7351	476	400	28	89	A
7475-T7351	496	414	40	145	A
7050-T7651	552	469	33	130	C

In order to improve the aerodynamic performance, business jets are required to adopt complex wing configurations using multiple cross sections, in which contours in span and chord directions are intricately combined. Furthermore, wings possessing such complex contours need to be formed in one piece so as to effectively reduce cost and weight. These are the main reasons for selecting the age forming process. The specimens for this study were formed into convex-concave double curvature configurations to simulate the inboard area of a lower wing.

3. Experimental Results and Discussion

3.1 Forming Test

Age Forming

The age forming test was performed as follows: First, a specimen that had been machined out in an integral structure was placed on a tool with a predetermined contour and pressed against it by vacuum bagging, wherein the specimen was sealed in a film. Subsequently, the specimen was heated under pressure in an autoclave, and after aging, it was cooled down and released from the tool.

Aging Condition

The aging condition to attain T7351 temper for 7475 aluminum alloy is found in the public heat treatment specifications for aerospace aluminum alloys, but it is only for the change of temper from W temper to T7351. The time needed for this aging is more than 24 h, which is undesirable from the standpoint of manufacturing cost. For that reason the aging condition to attain T7351 temper for 7475 aluminum alloy, which resulted in an aging schedule of 8 h at 177°C to change the temper from T651 to T7351. It was confirmed that the 7475 alloy aged under this condition satisfied the 7475-T7351 aluminum alloy static strength specifications, hardness, and electric conductivity as described in the public aerospace materials specifications.

Tool Contour

The forming tools used for the test were configured by convex-concave double curvatures so that they simulated the configurations of the inboard section of the lower wing, which are difficult to form. The curvatures of the tool contours in span and chord directions are shown in Table 2.

Table 2: Forming tool curvature.

Span curvature (mm)	48000	25000	10000	8000	8000
Chord curvature (mm)	1200	800	3000	4000	1300

Specimen

The specimen was 1000 mm long and 400 mm wide with an integral skin cross section having a shape similar to that of a typical inboard wing section of a business jet. The amount of springback was measured at the center of the length and width of each of the specimens after age forming was performed. The configuration of each specimen was measured after age forming and compared with that calculated by finite element method (FEM) for each tool.

3.2 Results of the forming test

Figure 3 shows some of the specimens after age forming. All specimens were formed successfully in convex-concave double curvature configurations with their stringers showing no buckling. Excellent repeatability was achieved for each tool. The amount of springback for each tool is shown in Table 3. Springback in the span direction tended to increase with increase in tool curvature in that direction. Similar tendency was observed for springback in the chord direction.

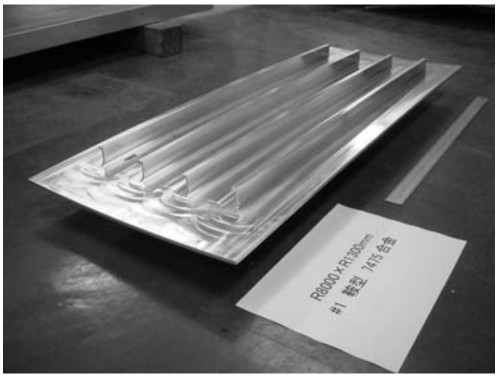

Figure 3: Specimens after age forming.
(Span tool curvature: 8000 mm / Chord tool curvature:1300 mm)

Table 3: Results of the forming test.

Tool curvature (mm)		Average springback (%)	
Span contour	Chord contour	Span contour	Chord contour
48000	1200	70	61
25000	800	60	58
10000	3000	54	65
8000	4000	55	67
8000	1300	55	51

3.3 Springback Prediction

The following approach was adopted to predict the amount of springback after age forming. To begin with, a new parameter called age forming equivalent modulus E_{eq} was introduced. As schematically shown in Figure 4, E_{eq} is calculated from (1) creep data obtained when the alloy 7475 is aged from T651 temper to T7351, (2) internal stresses calculated by FEM analysis at the time of vacuum bagging, and (3) residual strains after age forming. Together with Young's (elastic) modulus at room temperature and Poisson's ratio, this new parameter E_{eq} is used for the FEM analysis to predict the configuration of a specimen after age forming. As illustrated in Figure 5, the following steps are considered for the analysis. First, a specimen of room temperature elastic modulus E_{RT} is forced to deform to a predetermined configuration (RUN 1). The reverse forces that are required for the deformation are calculated from RUN 1. Second, the calculated reverse forces are imposed on a specimen of age forming equivalent modulus E_{eq} (RUN 2). The configuration obtained by RUN 2 is the theoretical prediction of specimen configuration after age forming.

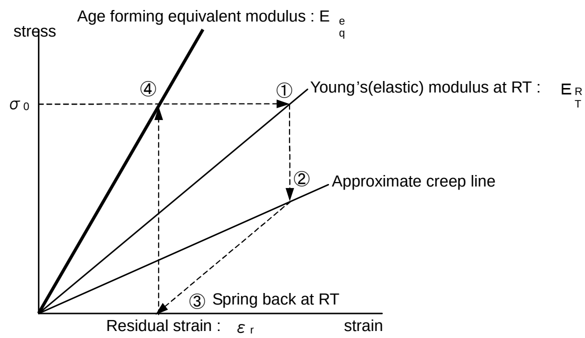

Figure 4: The concept of age forming equivalent modulus.

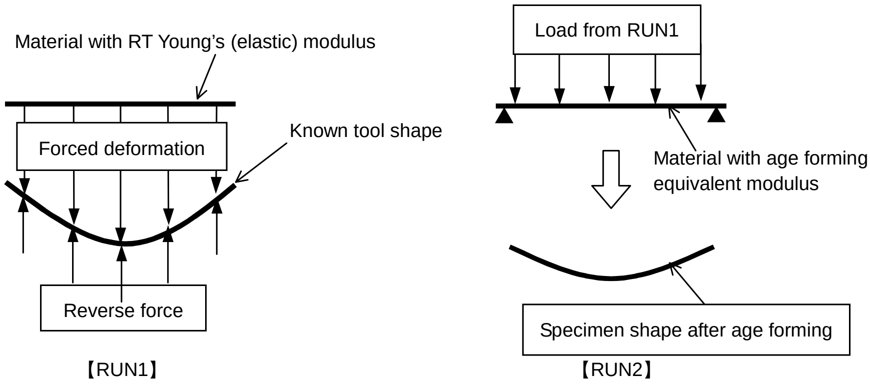

Figure 5: Analytical steps for shape prediction after age forming.

3.4 Comparisons of Experimental Results and Analytical Predictions

The amounts of springback obtained from the forming test and those predicted by the analysis are plotted in Figure 6 as a function of the contours' curvature in the span direction of forming tools. Figure 7 shows both the measured and the predicted amounts of deformation in the cross section along the span of a test piece when it was formed with a tool whose contour curvature in the span direction was 10000 mm. Although the experimental results and analytical predictions of springback and deformation agreed reasonably well, there were still noticeable differences between the two. The accuracy of the prediction of springback may be improved by taking into account the effects of curvature-dependent shearing forces in both the span and chord directions and integrating them into a new parameter.

The amount of springback in the span direction tended to increase with an increase in the curvature of tool contour. The maximum difference between the experimental and the predicted values for the amount of springback was approximately 7%. A similar result was obtained in the chord direction. These results suggest the possibility of accurately predicting the configuration or springback after age forming by the analytical tool developed in this study.

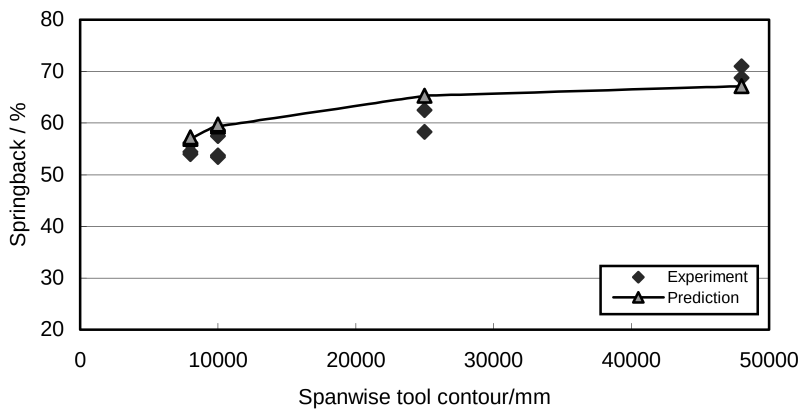

Figure 6: Comparison of experiment and prediction in the amount of springback (along span).

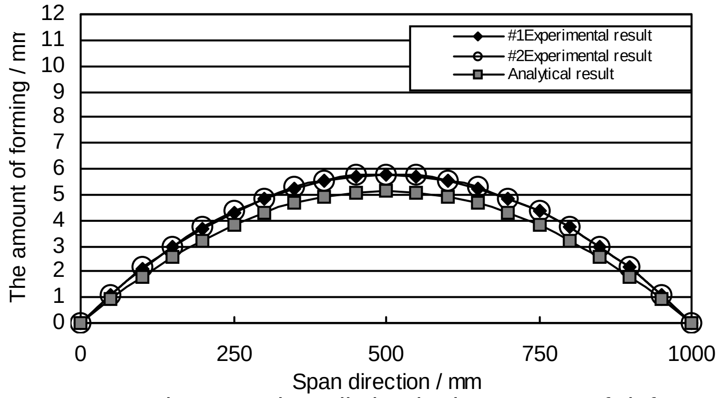

Figure 7: Comparison between experiment and prediction in the amount of deformation(curvature of contour of tool in span direction: 10000 mm).

4. Conclusions

The possibility of age forming double curvature integral wing skins was studied and the following results were obtained:

(1) Age forming could be used to form double curvature integral wing skins with good repeatability by following an aging schedule developed to age 7475 aluminum alloy from T651 to T7351.

(2) The preliminary forming test confirmed the accuracy of the analytical tool developed to predict springback.

The above results established the cost effectiveness of double curvature skins in integral forms, their age forming, and the analytical tool to reduce tool trial and alteration steps therefore reduces the tool development cost.

Acknowledgement

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References

[1] H. Brewer, Age Forming Integrally Stiffened Aluminum Aerospace Structures in an Autoclave, AIAA-89-2087, 1989, AIAA/AHS/ASEE Aircraft Design, Systems and Operations Conference.

[2] H. Takehisa, The application of age forming for aircraft wing skin, Journal of the JSTP, vol.44, no.510 (pp.687 – 690), 2003.

[3] MIL-HDBK-5, Metallic Materials And Elements For Aerospace Vehicle Structures, 1998, Aeronautical System Center.

[4] Damage Tolerant Design Handbook, 1994, CINDAS/USAF CRDA Handbooks Operation, Purdue University.