

ADVANCED METHOD AND PROCESSING TECHNOLOGY FOR
COMPLICATED SHAPE AIRFRAME PART FORMING

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SUMMARY

Slow deformation modes of forming give considerably higher residual fatigue life of the airframe part. It has been experimentally proven that fatigue life of complicated shape integral airframe panels made of high strength aluminium alloys is significantly increased after creep deformation process. To implement the slow deformation mode forming methods, universal automated equipment was developed.

Multichannel forming systems provide high accuracy of airframe part shape eliminating residual stresses and spring effect. Forming process multizone control technology was developed and experimentally proved that static/fatigue properties of formed airframe parts are increased.

1. Slow deformation processes.

It was experimentally established for many structural materials including aluminium and titanium alloys, alloys based on iron, that with the decrease of the loading velocity, the maximum strain value at the moment of material sample failure increases. This effect became more significant with the increasing of temperature [1].

Metallographic investigation of specimen microsections confirms that for high loading speed pores at the grain interfaces can be clearly observed. For specimens that were deformed at large loading speeds, pronounced porosity can be observed. On microsections of the specimens deformed up to the same values of elongations at low loading speeds these phenomena could not be seen.

A slow deformation process gives sufficient time for local peak stresses relaxation. As a result structural parts that are treated by a slow deformation process have a minimum damage of material at the production stage and have significantly better fatigue and durability properties.

2. Creep forming, thermal fixation technique.

Microscopic creep deformation has several features that are distinctive from instantaneous microscopic plastic deformation. Instantaneous plastic deformation is concentrated in narrow batches of sliding planes of dislocations, where the local shear value is very large. The areas that are located between those batches and are mostly part of the volume remain undeformed. The under creep mode sliding process is going more evenly in the many closely located atomic planes and relative displacements of neighbour planes are smallish (several distances between atoms). So creep deformation is going practically simultaneously in a whole volume of material [2]. The creep slow deformation process was successfully applied for the forming of airframe parts such as stiffened panels.

For monolithic stiffened panels made of high strength aluminium alloys mechanical properties after the creep forming process are significantly better than after instantaneous plastic forming [1].

Durability and fatigue strength of aluminium alloy integrated panels after creep forming are increased. Fig. 1 illustrates this for aluminium alloy AK4-1.

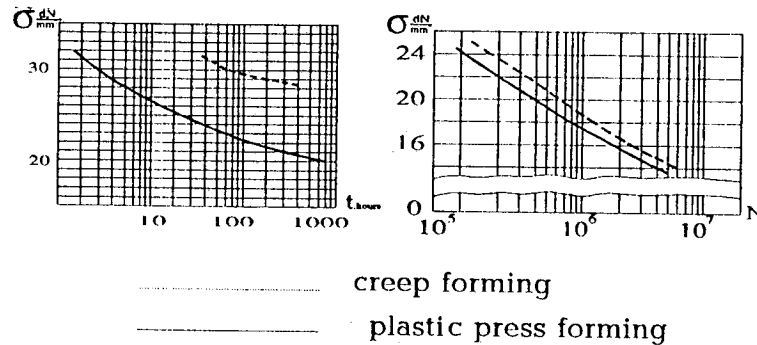


Fig. 1. Durability and fatigue strength of panels made of AK4-1 aluminium alloy.

The most widely used method of creep forming was called thermal fixation technique. This technique involves heating the blank to a specified temperature and then pressing it to the fixed surface and holding it for a determined amount of time in order to obtain a desired form. Different kinds of tools are used for loading airframe parts during thermal fixation: correspondingly shaped ribs, pads, vacuum bags, etc. Usually thermal fixation is provided inside a relatively large furnace.

In fig. 2 the airframe wing panel that was manufactured with thermal fixation technique is demonstrated.

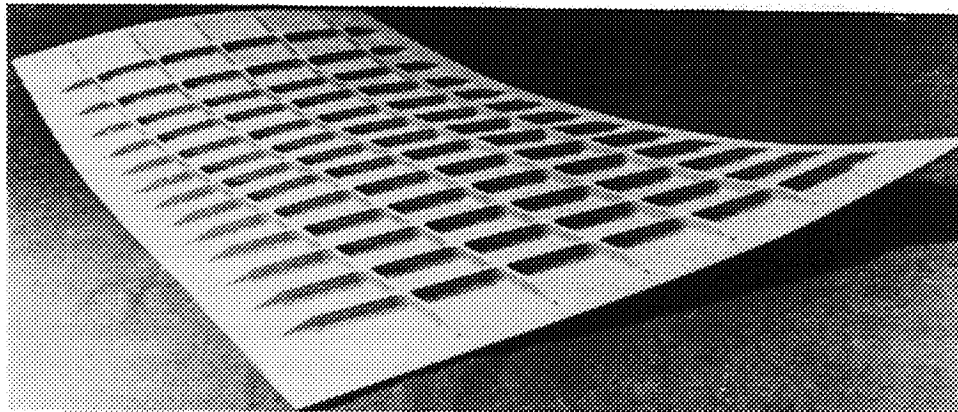


Fig. 2. Airframe wing panel.

The thermal fixation technique significantly improves the accuracy of forming and also reduces the residual stresses comparatively with other techniques. Thermal fixation provides forming a complicated shape airframe panel with double curvature [1]. However, thermal fixation does not entirely eliminate residual stresses or the spring effect and requires the manufacture of special loading and forming tools for each type of airframe panel.

Disadvantages of a thermal fixation technique originate from its advantage; that is, simplicity. In a thermal fixation technique we have only two parameters for process control: overall load (pressure) and average temperature. It is impossible to provide local monitoring and control of part shape and

residual stresses, local control of loading speed, local control of temperature, etc. So further development of creep forming method involves multichannel control of loading, relaxation, heating and cooling.

3. Local loading and relaxation

First of all it is necessary to measure and control the forming force in each zone of the workpiece. Precise forming of the workpiece must be achieved and maintained in conditions when all these forming forces are equal to zero. Forming forces are proportional to the force and moment reactions of the internal stresses in the corresponding zone of the workpiece. If these forces are equal to zero, then the actual or residual stresses inside the workpiece are self-equalizing or equal zero. Only the values of the forming forces can give us correct information on the internal stresses. Strain gauges are not useful in this application because the strain value contains significant creep component and thermal elongation.

Self-equalizing stresses do not produce resulting forces or moments and have no influence on the form of the workpiece. During annealing these self-equalizing stresses decrease to a minimum very close to zero.

Let us consider the beam model local loading control during a creep forming process. Supposing that temperature is constant during a process and across the beam and creep deformation velocity can be described by the following approximation [2]:

$$\frac{d\varepsilon_{cr}}{dt} = \varepsilon_n \left[\frac{\sigma(t)}{\sigma_n} \right]^n \cdot y, \quad (1)$$

where ε_{cr} - creep deformation,

y - distance from neutral axis of the beam,

$\varepsilon_n, \sigma_n, n$ - constants,

$\sigma(t)$ - time dependent part of stress σ ,

$\sigma = \sigma(t) \cdot y$,

Supposing that part of the beam was loaded by bending moment M that causes only elastic strain, and after that, curvature χ_0 of the beam was fixed and the beam is subjected to a creep relaxation process.

$$\sigma = E \cdot [\chi_0 - \chi(t)] \cdot y, \quad (2)$$

where E - modulus of elasticity,

$\chi_0 = \frac{M}{EJ}$ - initial beam curvature,

$\chi(t)$ - beam curvature relaxation during creep deformation process,

$J = \int_S y^2 ds$ - beam cross section area S moment of inertia.

From equations (1) and (2) follows:

$$\varepsilon_{cr} = \chi(t)y \quad (3)$$

$$\frac{d\chi(t)}{dt} = \varepsilon_n \left[\frac{\sigma(t)}{\sigma_n} \right]^n \quad (4)$$

$$\frac{d\sigma(t)}{dt} = -E\varepsilon \left[\frac{\sigma(t)}{\sigma_n} \right]^n \quad (5)$$

Solution of equation (5) follows:

$$\sigma(t) = \left\{ \frac{1}{(n-1) \left[E\varepsilon_n \left(\frac{1}{\sigma_n} \right)^n \cdot t + \frac{1}{n-1} \cdot \frac{1}{\sigma_0^{n-1}} \right]} \right\}^{\frac{1}{n-1}} \quad (6)$$

where $\sigma_0 = \sigma(t)$ at $t = 0$.

From equations (2) and (6) it is possible to compute $\chi(t)$:

$$\chi(t) = \chi_0 - \frac{\sigma(t)}{E} \quad (7)$$

With time growth the value of $\sigma(t)$ is tending to zero and $\chi(t)$ is tending to χ_0 .

Actual bending moment $M(t)$ can be expressed by equation (8):

$$M(t) = \int_s \sigma y ds = M - EJ\chi(t) \quad (8)$$

So $M(t)$ is tending to zero with time growth because $EJ\chi(t)$ is tending to M .

This simplified process model illustrates the importance of monitoring and control of local loads as a tool to control internal stresses and velocity of forming process and to provide high forming accuracy. Whole forming procedures may be divided by several sequential stages of loading and

relaxation for each local zone of workpiece as shown in fig. 3.

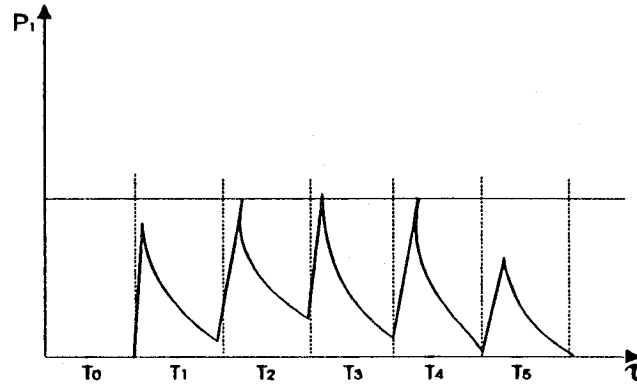


Fig. 3. Loading and relaxation stages during forming process.

4. Local temperature control.

Velocity of creep deformation is very sensitive for temperature, especially for aluminium alloys. It is possible to control a forming process by properly adjusting temperatures in local zones of the workpiece instead of load values control.

In fig. 4 a curve of equal influence of temperature and load (stress) on velocity of creep deformation is presented.

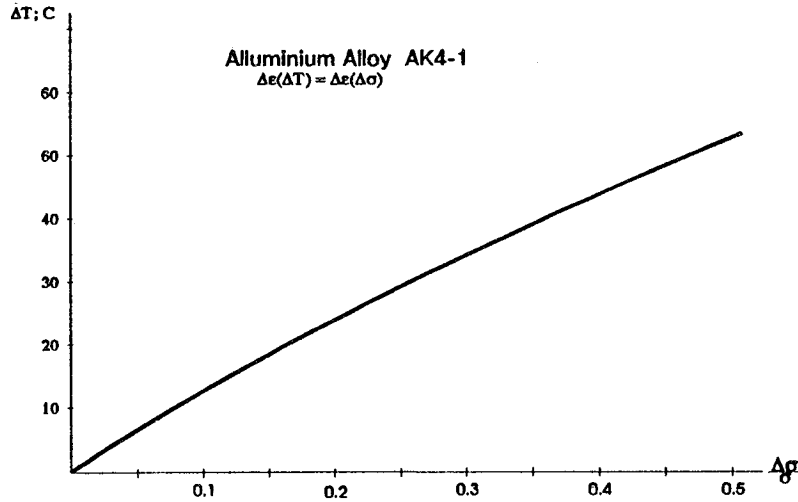


Fig. 4. Relative influence of temperature and load on creep deformation velocity.

For aluminium alloy AK4-1 a temperature variation of 10°C is equivalent to 7.5% of local load variation.

5. Multichannel creep forming process control.

Multichannel control procedure consists of:

- program forming in each zone of the workpiece by electrohydraulic or electromechanical

- actuators with displacement feed-back control mode
- monitoring the force of each actuator
- halting the program forming when any actuator force reaches the corresponding maximum allowable values
- waiting until all actuator forces reach the corresponding minimum allowable values
- starting the program again and repeating the forming process
- halting and waiting until the desired form of the workpiece will be obtained

The maximum and minimum allowable values of the force are dependent on the stage of the forming process, i.e. displacements of actuators.

To optimise the above procedure some useful operations can be added:

- halting the program selectively for single actuator or for a determined forming zone of the workpiece (i.e. several actuators of this zone)
- increasing the temperature in the zone where forming forces are fewer than the prescribed values during the initial stage of waiting period. This will speed up the relaxation process in that zone
- decreasing the temperature in the zone where the relaxation process is significantly faster than in other zones

Facility for multichannel creep forming of complicated shape airframe parts consists of multi-sectional housing in the form of a spatially flat-type surface [1]. Flat sections of the housing are connected to each other by hinges. Several sections are fixed stationary.

Movable sections are used when the workpiece has large geometrically nonlinear deflections. Movable sections are connected with individual drives.

Forming force drives are installed at fixed angles on the flat sections of the housing. Heating and cooling devices are fixed into position on the flat sections of the housing. Forming force drives have displacement and load gauges that are connected with forming force drive controllers. Each section of the housing can serve several forming force actuators and several zones of heating and cooling means. In fig. 5 the block diagram of a multichannel control system is presented.

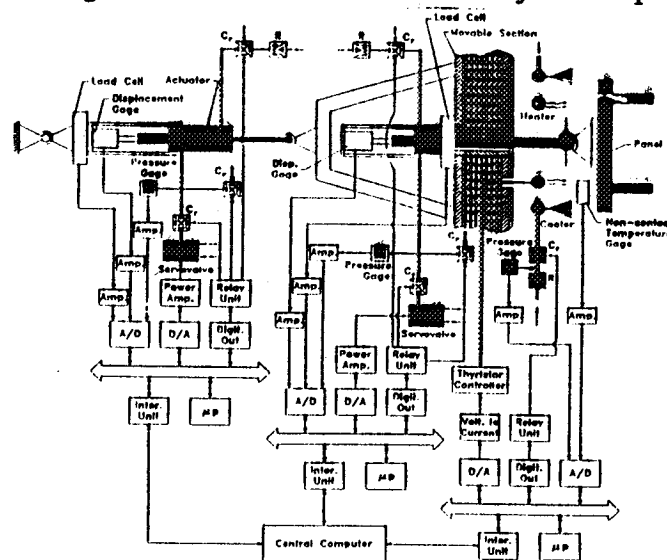


Fig. 5. Multichannel process control system.

A multichannel creep forming procedure was successfully tested on the experimental facility. Now the industrial facility for airframe panels with width up to 2m is under construction. Length of panel is not critical because the facility is modular in the longitudinal direction.

Despite a relatively high cost of equipment, a multichannel creep forming process has several important advantages:

- the same facility can be used for forming different airframe parts (with different shapes or different materials or structures).
- manufacturing of pressforms is eliminated
- precise forming without spring-effect
- high structural quality of forming airframe parts (increase of durability and fatigue life, resistance to impact)
- applicability for airframe parts of large sizes
- possibility of forming airframe parts with changing sign double curvature shape with large geometrically nonlinear forming deflections

One interesting and prospective application of such facility is the forming of pressform panels for composite material airframe parts manufacturing.

Experiments were provided for welded panel creep forming. During the creep forming process welding stresses significantly decrease and, consequently, forming quality and structural characteristics are increased.

Conclusion

Advanced creep forming technology with multizone control of loading and temperature provides significant quality improvements of complicated shape airframe parts and gives more possibilities for airframe designers and production engineering.

References

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2. U. N. Rabotnov, S. T. Mileico, "Short time creep," Nauka publishing house, Moscow, 1970.