# A NEW PRODUCTION TECHNOLOGY FOR COMPLEX-SHAPED STRUCTURAL ELEMENTS "CREEP FORMING"

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## Abstract

Creep forming is a new technology which enables complex shaped elements, such as monolithic panels of double curvature (used in the aircraft industry), to be produced with very high accuracy. The forming is implemented by means of a multichannel control system for heating and deformation of blanks such as solid monolithic and welded stiffened panels made of aluminum, titanium alloys and steels.

## I. Material Response under Creep Deformation

The material pressure treatment - forging, stamping, forming, etc. - is characterized by the creation of irreversible residual strains. The modes of material pressure treatment with several percent per second of deformation speed are widely spread in the industrial environment. However, these modes cannot be applied to high strength structural materials since the formed part may reach its own fatigue life limit during the treatment, as occurs during the manufacturing stage.

Material pressure treatment can be improved in two ways:

1. The time duration of load action on material is reduced simultaneously with the increase of the load force applied to the material (impulse treatment).

2. The duration of the load action on material is increased from a fraction of a second to minutes or even hours (time-dependent strain).

This paper considers and discusses the second point. It was experimentally established for many structural materials including aluminum and titanium alloys, alloys based on iron, that with the decrease of the deformation speed, especially at high temperatures, the strain values limits (to the moment of failure) increase, whereas the work of plastic strains remains at an approximately constant value. This is shown by the stress-strain curves in fig. 1 for aluminum alloy AK4-1.

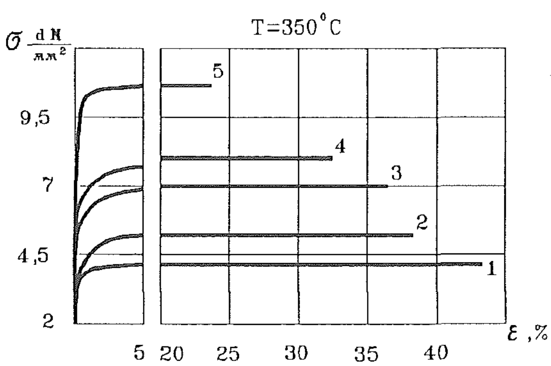


Figure 1. Stress-Strain on Aluminum Alloy (AK4-1)

If we proceed with the energy strength theory, assuming that accumulated damage is proportional to dispersed energy, then slow deformation modes give considerably higher residual fatigue life of the treated part.

It was understood during tests that the growth of the total strains at low loading speeds can be explained in the following way. During the loading process inside the material at the grain interfaces, stresses appear with values considerably different from average microstresses. At high temperatures and slow loading at the grain interfaces, the peaks have sufficient time to relax. Under high loading speeds at the grain interfaces, large peak microstresses can appear. As a consequence, microcracks (centres of local material failure) form in the material resulting in the rapid decrease of its total fatigue life. Further metallographic investigations confirmed these facts.

On the microsections of specimens deformed up to a specific value at high speeds, pores at the grain interfaces can be clearly observed and the material structure has an irregular shape. At large values it can be seen that the specimen has a mat tinge with pronounced porosity. On microsections of the specimens deformed up to the same values at low loading, these phenomena could not be seen.

A comparison is given in table 1 of the strength of solid monolithic panels made of aluminum alloy AK4-1 under cold plastic deformation and of the same panels under creep conditions.

| Production Technology | Mechanical Properties | | |
|---|---|---|---|
| | $\sigma_b$ | $\sigma_{02}$ $\frac{dN}{mm^2}$ | ε% |
| cold plastic deformation | 41.5 | 33 | 4 |
| creep mode | 44.3 | 37.3 | 7.5 |

Table 1. Comparison of Cold Plastic Deformation and Creep Mode Techniques

It has been experimentally proven that the strength of impacts can considerably increase after the creep deformation process. It was also demonstrated that at sufficiently high temperatures and low deformation speeds plastic component deformation does not occur and a deformation mode similar to superplasticity occurs. This results in: minimal damage of material at unit production stage; internal stresses in material have sufficient relaxation time (to negligible small values) during the slow thermomechanical loading; after loading is terminated no residual stresses occur; and slow processes are more easily automated.

## II. Forming Techniques of Complex-shaped Structural Elements

In modern structures of aircraft and ships, sheet rolled stock, profiles, solid milled and pressed ribbing panels are widely used. The existing technological forming processes such as sequential bending, knocking out and others, employ hard manual labour and a large volume of finishing work. These processes do not produce large and complex curvature elements according to today's demand for high accuracy. The most effective way of increasing the accuracy without applying manual finishing work, is to use deformation processes based on slow thermomechanical loading of metal.

During the initial stages of development of the creep forming technique, the most widely used method was called the 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 so to take the desired form [1]. This technique significantly improves the accuracy of forming and also reduces the residual stresses (see table 2 and fig. 2).

| Technique of Integral Panel Forming | Residual stress $\frac{dN}{mm^2}$ |
|---|---|
| sequential bending | 21.8 |
| bending - rolling | 12.65 |
| thermal fixation | 3.5 |

Table 2. Panel Forming Techniques - Residual Stress

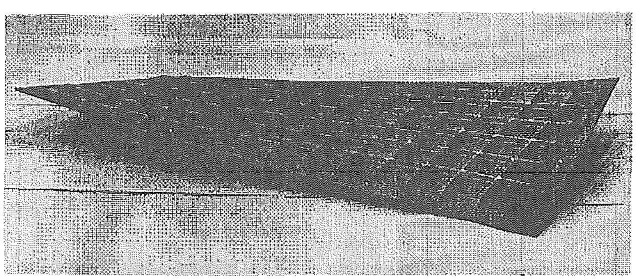

Figure 2. Panel Manufactured with Thermal Fixation Technique

However, this method does not entirely eliminate the need for manual finishing work and requires the manufacture of special equipment for each type of panel.

These disadvantages can be eliminated with the new creep forming technique introduced in this paper. The main feature of creep forming is the division of the blanks into individual heating (and cooling) and loading zones according to their parameters and mechanical and thermophysical properties. Individual programs for heating, cooling and deformation have been designed for each zone. The whole deformation process is divided into a series of steps. For each step in each zone, the load value is set which then must relax within the given time interval during that step. The creep forming technique holds many significant advantages and makes it possible to completely automate the process.

## III. Universal Equipment for Creep Forming

To implement the Creep Forming technique, universal equipment is used consisting of a multichannel electrohydraulic loading system and a multichannel heating/cooling system. (Some papers discuss the application of an electromechanical drive for the deformation process [2]). Let's consider the composition of the universal equipment and the characteristics of its functions using the example of a facility for monolithic panels forming (see fig. 3).

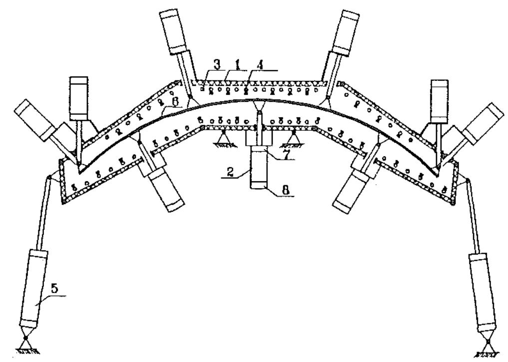

Figure 3. Monolithic Panel Forming Facility

Attached to frame (1), composed of fixed and movable parts, there are hydraulic jacks (2), heaters (3) and devices for cooling (4). The movable parts of the frame are moved by hydraulic jacks (5). The frame is thermally insulated and there is space inside designed for a thermal chamber. The blank panel (6) is bent by the loads produced by the hydraulic jacks equipped with load cells (7) and displacement gages (8).

The infra-red heaters (3) are controlled by thyristor devices with temperature feedback. The measurement of temperature in every zone can be carried out by contact and non-contact methods developed especially for these conditions. Cooling is carried out with jets of cold gaseous nitrogen or with a nitrogen-air mixture.

The measurement of displacements of the blank during the deformation process is carried out not only through the operating rods of the hydraulic jacks but also by complementary displacement gages.

Control of the loading is performed on the specified program of displacement for each step. Since the blank deformation process is carried out at high temperatures in creep mode (acting stresses), the deformation loads are very low. The time interval at each step of the deformation process is determined by the time of relaxation. The deformation process terminates when the specified displacements of the blank are attained, thus, the loads in all the hydraulic jacks are close to zero.

After completing the deformation process, the heat treatment at fixed displacements of the panel then commences monitored by the occurring loads.

The initial position of the movable parts of the frames is shown in fig. 3 by the thick black line. At relatively small displacements of the panel, movable parts of the frame are not relevantly used. In cases of large displacements and complex-shaped panels the frame may consist of many movable parts with separate actuators.

With the aid of software specially developed for the design and adjustment of technological processes the following problems are solved:

- determination of required deformation loads for specific geometry of a panel;
- closed loop computer simulation of forming process for: optimization of loading and heating modes; quality control; acceleration of the process for readjustment of equipment for panel modification. The software of the control system and data acquisition are based on an industrial scale.

## IV. Advantages and Disadvantages of Creep Forming

The main disadvantage of the new Creep Forming technique is it demands a longer term for the manufacture of products. This disadvantage may not be so significant for the aircraft and shipbuilding industries as apposed to the automotive industry where mass production is demanded. Although this obstacle cannot be superseded there is a good potentiality of the technique being applied in the automotive industry or small series manufacturing (development of prototypes) with different modifications with the use of universal equipment.

Advantages of the Creep Forming technique used in the manufacturing processes described above include:

- low deformation loads;
- heavy press equipment is not required;
- possibility to combine all significant stages of manufacturing processes into one plant eg. forming, heat treatment, corrections;
- increase of static/fatigue strength of parts;
- universality of equipment - parts that differ in shape and properties can be manufactured by same facility;
- higher accuracy;
- complete automation of manufacturing process;
- modularity of equipment - possibility to manufacture large-sized parts in plants consisting of the same type modules.

## V. Conclusion

Creep forming is now out of the stage of investigation and is moving into the stage of industrial application. The new technique holds many advantages for smaller series manufacturing as apposed to current methods. The introduction of the technique will more particularly concern designers and manufacturers of the aircraft industry.

## References


1. M. Stejskal. High temperature vacuum creep forming fixture. U.S. patent 3739617, 1973.

2. G.T. Pinson. Apparatus for forming sheet metal. U.S. patent 4212188, 1980.