Conference Paper

Numerical and Experimental Study of Multi-Point Forming of Thick Double-Curvature Plates from Aluminum Alloy 7075

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Abstract

The paper describes various rod type work tools intended for forming parts and their design peculiarities and technological processes they are used in. We present the device for multi-point forming thick double-curvature plates with the use of reconfigurable core punch and die in large temperature and speed range. The results of finite element modeling of forming and machining process are demonstrated. It is revealed that heating the work piece results in pressing of the rod into the work piece in the areas of maximum pressure. The depth of pressing depends on mechanical behavior of the material at forming temperature and force to forming rods. The paper presents the results of experiments on developing of multi-point forming plates.

Keywords: multi-point forming, reconfigurable tooling system, thermoforming, sheet metal, spring-back, FEM analyses, aluminum alloy 7075

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1. Introduction

The aircraft engineering development community is moving in the direction of requiring greater efficiency, economy, and reliability of the modern aircraft. These requirements are associated with a decrease of materials consumption for the structural system, an increase of the strength-to-weight ratio and stiffness of airframe parts, and the use of high-strength and difficult-to-deform alloys.

Traditional manufacturing technologies associated with monolithic panels usually consist of two stages. During the first stage, the internal engraving of the panel work-piece (its fins) is created. The fins are usually fabricated by milling the primary blanks from plate stock. During the second stage, the panel is given an aerodynamic shape by bending the finned work-piece on the press. Three-point bending or rolling technology is used for the bending process. The optimized method of application for the three-point bending scheme to manufacture the aircraft panels with double curvature is presented in Ref. [1].

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Zn	Mg	Cu	Cr	Fe	Si	Mn	Ti	Al
5.8	2.3	1.5	0.21	0.16	0.07	0.05	0.02	Bal.

Table 1: Chemical compositions of 7075 aluminum alloy (wt%).

Manufacturing parts from high-strength aluminum alloys provides a number of restrictions on conditions of heat treatment and ultimate deformation. It is experimentally shown in Refs. [2-8] that forming in the creep regime and at stresses not exceeding the elastic strength of material, provides higher residual strength resource and less damage of components compared to the method of conventional cold forging. It is shown in Refs. [9, 10] that panel formation in the creep regime is limited by deformation and demonstrates a large value of material spring-back. In Ref. [11] it is shown that the elevation of forming temperature beyond the creep temperature leads to further increases of material elasticity, but also resulting in changes to its structure.

Most of the research exploring the possibility of using the reconfigurable rod devices is aimed to develop the technology of work-piece manufacturing from thin sheet material. In Refs. [12-15] design features of rod systems are considered and the main approaches to definition of the loads acting on each rod element are proposed. Results of searches for the most rational form of rod element are also presented.

The use of multi-point forming (MPF) for manufacturing components with double curvature from thick plates has not been widely applied yet. Firstly, it is connected with large loads on each individual rod. The problem of the forming process for relatively thick plates with 10 mm thickness wais considered in [16, 17]. It is shown that at normal temperature-speed forming modes parts can be manufactured with a minimum spring-back and can be eliminated entirely by adjusting the rods positions.

The objective of this study is to determine the possibility of using MPF for manufacturing finned panels with double curvature of alloy 7075 at elevated temperatures.

2. Material Analysis

Alloy 7075 belongs to the group of wrought alloys of the system Al–Zn–Mg–Cu. The chemical composition is given in Table 1 [8].

One of the limiting factors in the multi-point forming of thick plates is the possibility of stability loss with some of the most loaded rods. The search for the optimal temperature-speed modes of deformation of parts made of 7075 alloy under creep conditions, which retain high strength characteristics of the material, was carried out by Gorevoy, Raevskaya, et al. [4-7]. Material deformation analysis in the creep regimes shows that the accelerated relaxation process of creep for alloy 7075 continues at the recommended temperatures of 160-180°C and ends after 1 hour of being held in the pre-deformed condition (Fig. 1). In such a narrow temperature-time range and at small strain rates, insignificant rate of creep strain is being accumulated, which is not enough for efficient forming of the plates with greater curvature.

It is obvious that changing the temperature and strain rate can lead to higher material plasticity and can reduce the rods load. A number of mechanical tests at various

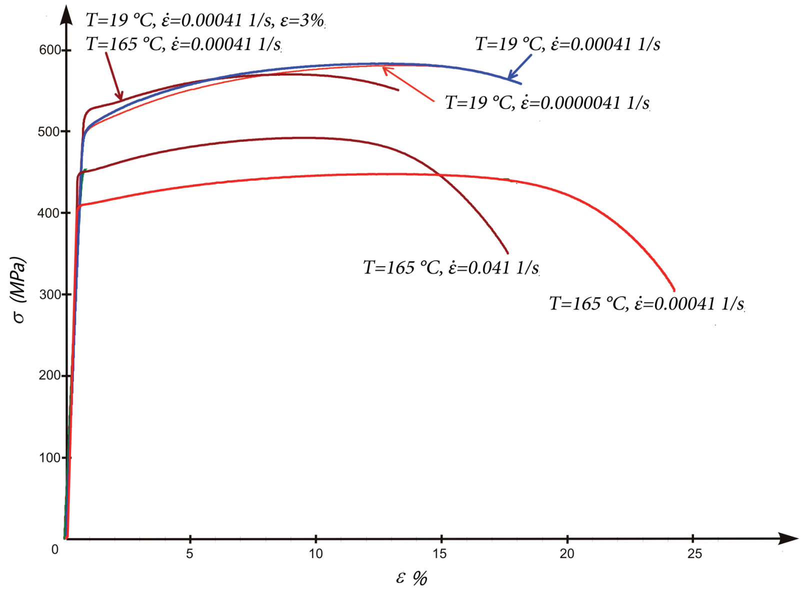

Figure 1: Stress-strain curves of 7075 alloy.

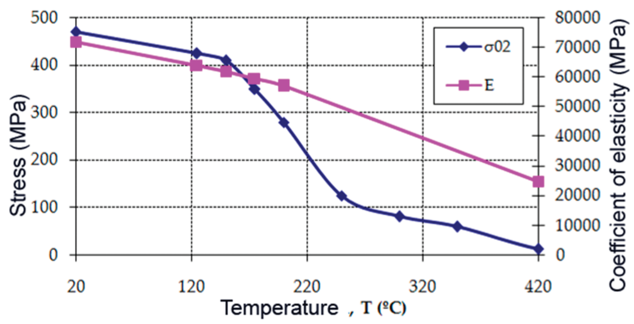

Figure 2: Temperature impact on the mechanical characteristics of alloy 7075.

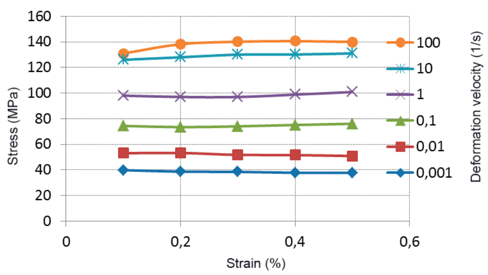

Figure 3: Stress-strain and strain rates ratio at 420°C for alloy 7075.

temperatures and strain rates have been performed in order to define the physical-mechanical properties of alloy 7075. The results are shown in Figs. 2-3.

Assessing the possibility of using the technology of thick plate forming by the MPF method was performed for the two modes of deformation. The first mode includes heating up to 165°C, required deflection forming, holding under load for 8 hours, slow cooling, and unloading. In the numerical model, the isotropic ideally plastic material with hardening power function is used. The second mode includes heating up to 420°C, required deflection forming, slow cooling, and unloading. In the numerical model, the

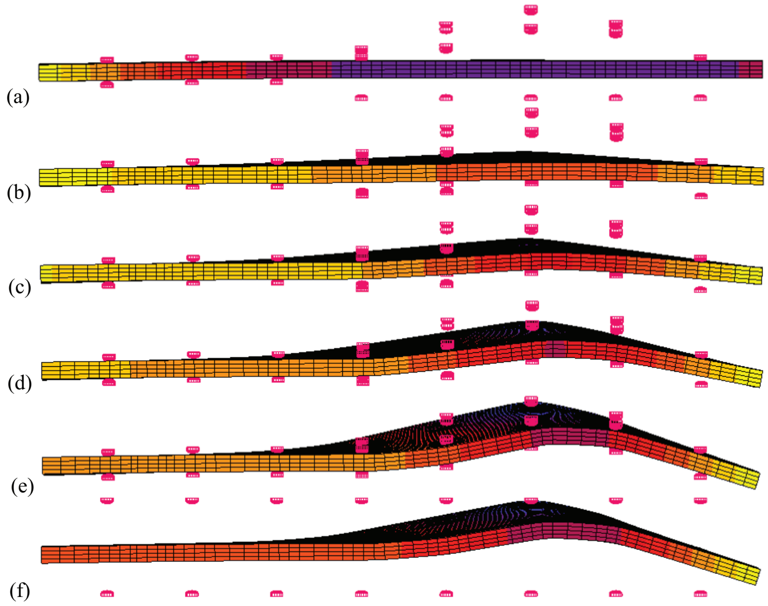

Figure 4: Stages of the work-piece deformation process: (a) loading; (b) 45%; (c) 60%; (d) 80%; (e) 100%; (f) unloading.

isotropic ideally plastic material without hardening with the dependence of characteristics on temperature is used.

3. Numerical Simulation

For modeling the process of forming the work-piece from plate with a thickness of 40 mm of alloy 7075, the multifactorial finite-element model (FEM) in the CAE system MSC.Marc has been developed. The numerical model of the work-piece has been represented using the FE meshwork with 4 node elements. The perfectly rigid body with a tip diameter of 30 mm has been utilized for the rod model.

Many studies are devoted to issues of FEM of material forming processes using MSC.Marc software products. Therefore, we will not dwell on the technical aspects of the model preparation and subsequent analysis. The behavior of material under the isolated influence of the rods system in work-piece forming (Fig. 4) was simulated in the calculation process. We have analyzed the results of internal stresses distribution in the material during and after load application.

As a result of forming process simulation, it is determined that temperature elevations make it possible to reduce the load on each rod element. On the other hand, heating the work-piece changes its mechanical properties and under certain conditions rod indentation into the work-piece material occurs. While making the panels of required shape with account of the restrictions imposed on the forming process, indentation of the rod into the work-piece at a depth of 6 mm at the places with maximum rod pressure on the work-piece is observed (Fig. 5). Work-piece forming process simulation in the high-temperature molding mode with the use of steel gaskets showed the decrease in the depth of the jam (Fig. 6), not exceeding 3 mm. Therefore, to reduce indentation, it is recommended to use steel gaskets or special tips. Simulation

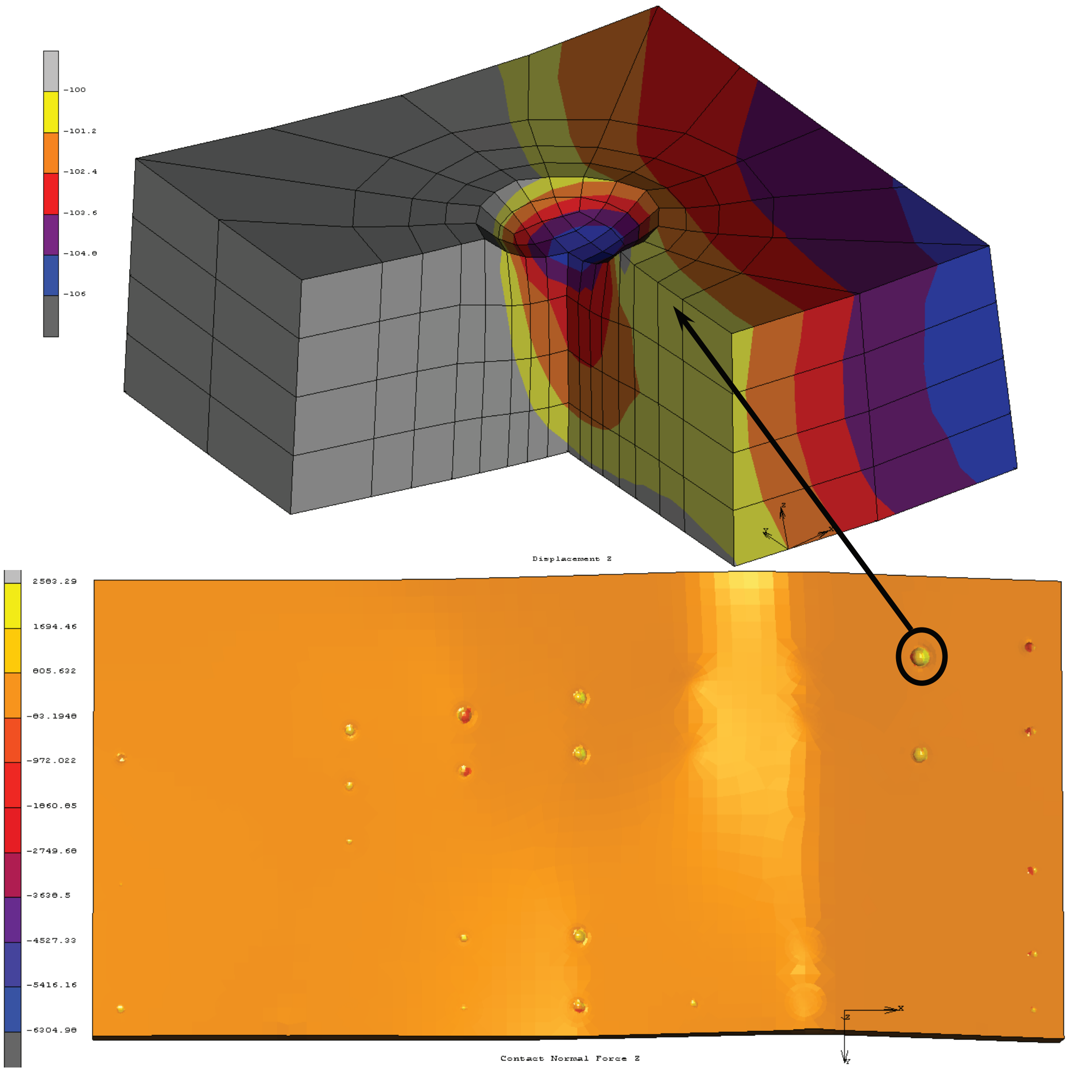

Figure 5: Rod prints on the work-piece aerodynamic surface.

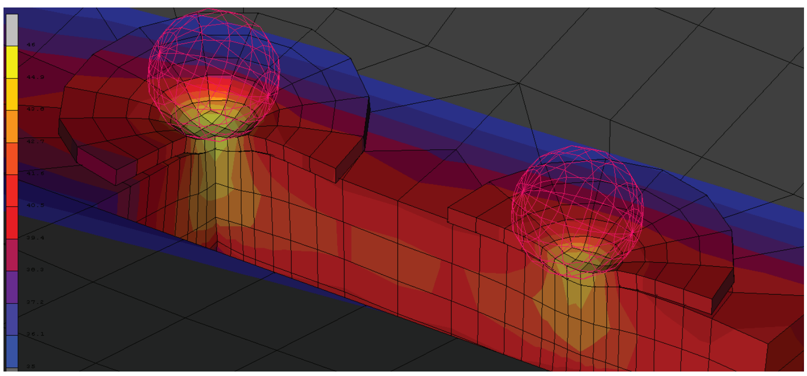

Figure 6: Prints on the work-piece up to 10 mm in diameter, up to 4 mm in height.

of unloading of the work-piece after thermoforming showed no indications of spring-back.

4. Experimental

To confirm the simulation results, field experiments on the evaluation of manufacturing technology for double-curvature panels made of aluminum alloy 7075 at a temperature of 420°C were carried out.

The results of forming confirmed the previously obtained results of numerical simulation. Comparison of rod prints revealed after modeling the deformation process with print on the experimental work-piece of alloy 7075 showed good correlation of developed model with the real experiment. Surface geometry scanning of experimentally formed work-pieces allowed the creation of an electronic model of a real work-piece, comparing it with the original geometry and the results of numerical simulation. Surface geometry scanning of the formed work-piece was carried out with 3D scanner ARTECEVA and laser radar.

5. Conclusion

The results indicated that for plates forming with double curvature, it is possible to use the rod type installation. Numerical control of multi-point forming process results in the high controllability of deformation process and the formation of complex geometric shape work pieces. However, for the most precise molding it is required to use as many pins as possible with tips providing larger contact area.

FEM developed in CAE system MSC.Marc makes it possible to simulate and efficiently evaluate each stage of the parts manufacturing technological processes.

The universal reconfigurable tooling systems of MPF, which make it possible to change the punch (the matrix) geometry in the forming process of large parts of complex spatial shape, has several advantages and is of great practical interest in the field of pressure shaping of materials. The installation design features still remain complex, expensive, and determined by the size and shape of parts and also power characteristics required for their deformation. Therefore, it can be argued that the niche of the reconfigurable multi-point forming tooling systems currently requires solutions that do not require complex devices creation, but still can provide the high precision of point rod elements positioning with expansion of their power range.

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