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FORMATION OF SELF-SEALING TUBULAR BLANKS WITH A MOVING EDGE

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The benefits and advantages of forming parts by having a moving edge during the forming operation are illustrated by using three parts as examples. The difficulties that arise with the use of this technology and ways to overcome those obstacles are discussed. Examples are also given of problems that can be resolved by using the technology.

Keywords: *pneumothermal forming in the superplastic regime, formation of tubular blanks.*

The formation of parts with complex elements from tubular blanks entails substantial reductions in thickness and the formation of appreciable strains that often exceed established limits. Thus, finding a method of shaping that keeps the thickness reductions and strains within the tolerance is an important problem [1, 2].

One method that has been proposed for solving this problem is the pneumothermal forming (PTF) of parts in the superplastic regime with a self-sealing sliding edge that moves along the surface of the fixture toward the deformation zone without any loss of contact. The movement of the semifinished product in the direction of the deformation zone alleviates tension due to gas pressure and thus decreases the thickness reduction (Fig. 1) [3].

This article examines examples that illustrate the modeling of the PTF of parts from a tubular blank made of titanium alloy OT4 at 900°C.

Shaping operations were modeled in the software system PAM-STAMP 2G, developed by the French company ESI Group. The modeling was done with the use of a simplified model that describes the behavior of a material in the superplastic regime

$$\sigma = K\dot{\varepsilon}^m,$$

where K is a proportionality factor; $\dot{\varepsilon}$ is the strain rate; m is the strain-hardening modulus; and σ is the stress.

Shown below are the parameters that alloy OT4 must have during superplastic forming in order to be modeled [4]:

Elastic modulus, MPa	112,000
Poisson's ratio	0.333
Density, kg/mm^3	$4.5\cdot10^{-6}$
Proportionality factor K, MPa	114.116
Strain rate $\dot{\varepsilon}$	0.004
Strain-hardening modulus m	0.38
Maximum elongation, %	400

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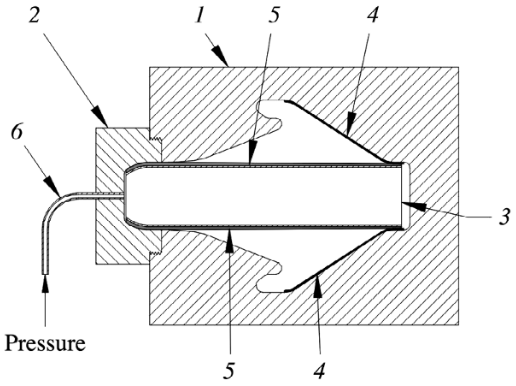

Fig. 1. Diagram of the operation of forming with a self-sealing sliding edge: *1*) fixture for shaping; *2*) hermetic cover; *3*) tubular semifinished product; *4*) anti-friction coating on the conical part of the fixture; *5*) anti-friction coating on the tubular semifinished product; *6*) pipe for supplying gas.

The modeling was done with the use of symmetric boundary conditions to shorten the computing time (we examined a model that represented one-half of the part obtained by dividing it through the plane of symmetry; the effect of the second half is accounted for by the boundary conditions).

Example 1. Conical shaping with "double rotation" in the flanged portion of the part (Fig. 2).

The forming operation was carried out using a tubular blank with a diameter of 50 mm and a thickness of 1.5 mm.

The modeling was done for two variants of the pneumothermal forming of parts:

variant 1 – without displacement of the ends of the semifinished product (two parts are formed simultaneously);

variant 2 – with the right end of the semifinished product sliding toward the deformation zone (one part is formed). The pressure of the gas acting on the semifinished product from its interior presses it against the conical surface of the fixture during the displacement of the edge over the duration of the forming operation and thus results in self-sealing of the product.

Figures 3 and 4 show the results obtained from modeling for variants with and without displacement of the semifinished product's edge.

There was a thickness reduction of 93.1% when the formation of the conical part was modeled with double rotation in the flange and no movement of the end. The thickness reduction was 57.9% when the modeling was done with the sliding of one end. Thus, the reduction in thickness was decreased by 37.9%.

Example 2. Cylindrical part with rotation (Fig. 5).

Use of the example of a cylindrical part made with rotation showed that this approach makes it more likely to be able to form elements with the use of a sliding edge.

A process for rotating tubes with differentiated heating in order to obtain similar elements was described in [6]. This process was modeled on a tubular semifinished product of titanium alloy OT4 with a diameter of 54 mm and a thickness of 1.2 mm. The deformation zone was heated to 900°C (it is assumed that alloy OT4 is in the superplastic state at such temperatures). The results of the modeling are shown in Fig. 6.

This technology has the following shortcomings:

1) the heating is done locally and in air;

2) it is not possible to form additional elements on parts on a cylindrical surface of revolution;

3) the process of monitoring the thickness of the rotated element is complicated; and

4) an upsetting force is needed.

Modeling the rotation of the above-described tubular semifinished product by pneumothermal forming in the superplastic state with a sliding edge showed (Figs. 7 and 8) that this results in a compressive force and that loss of stability in the form of corrugation occurs on the cylindrical element that is being formed by rotation. The loss of stability takes place in

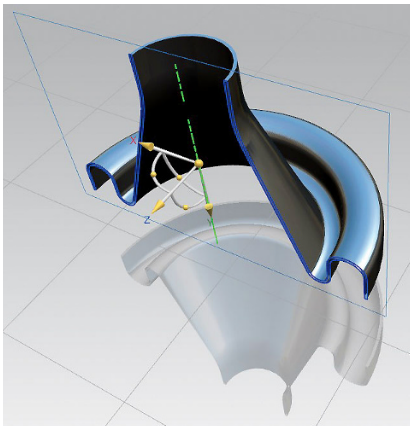

Fig. 2. Conical part with double rotation in the flange.

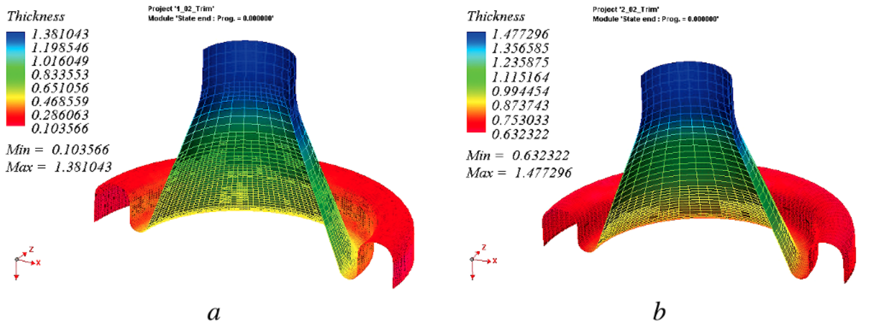

Fig. 3. Distribution of thickness over the surface of the part after forming: *a*) variant 1 (93.1% thickness reduction); *b*) variant 2 (57.9% thickness reduction).

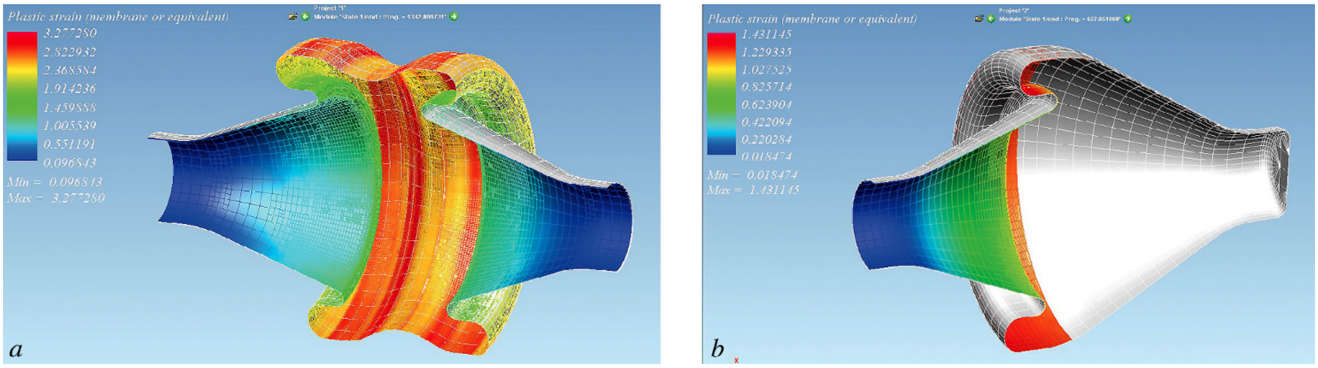

Fig. 4. Strain distribution over the surface of the semifinished product after forming: *a*) variant 1 (maximum deformation 327%); *b*) variant 2 (maximum deformation 143%).

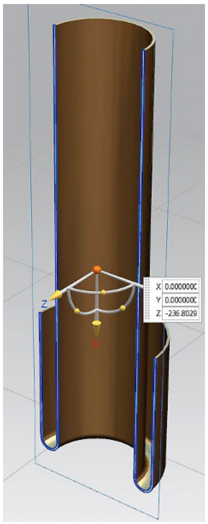

Fig. 5. Cylindrical part formed with rotation on the edge.

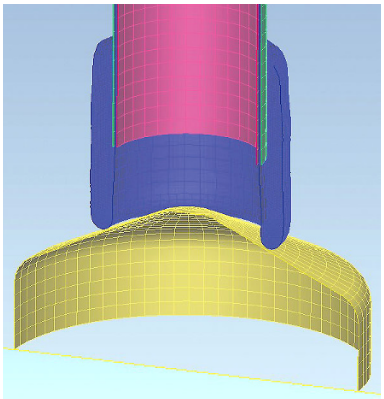

Fig. 6. Result from modeling the rotation of a tube with heating of the deformation zone.

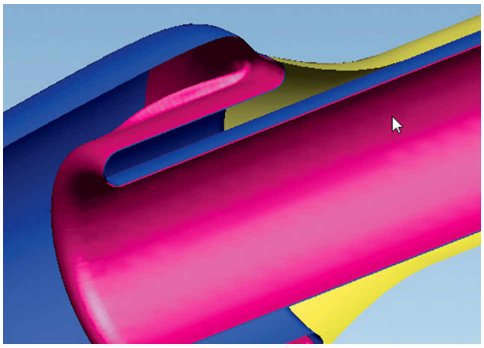

Fig. 7. Result from modeling the rotation of the tube with a sliding edge over the surface of the fixture.

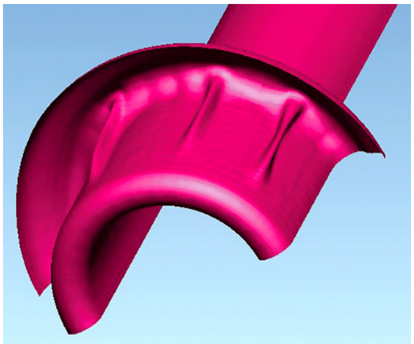

Fig. 8. Appearance of the part after forming.

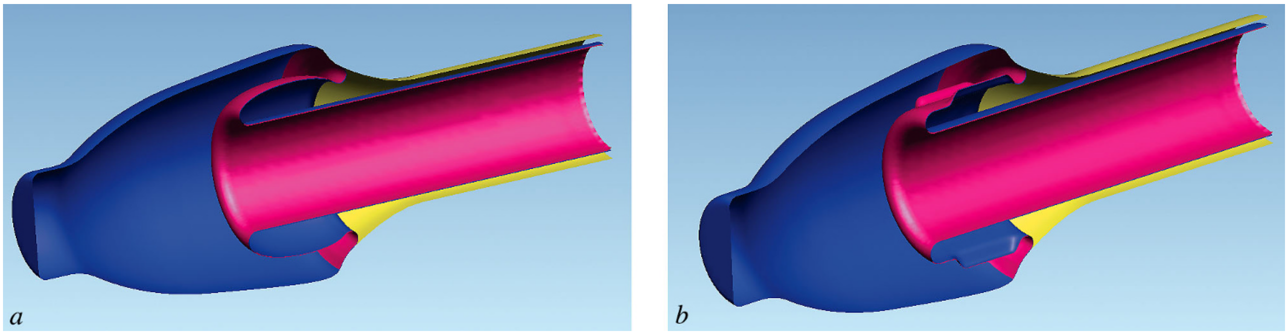

Fig. 9. Results obtained by modeling the PTF process to obtain a box-shaped rotated element (*a*) and a rotated element with straight segments (*b*).

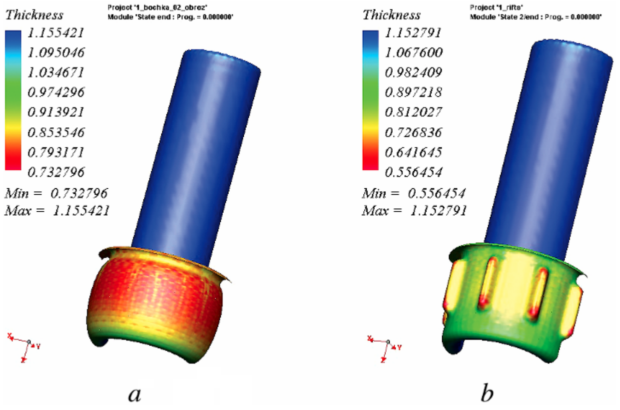

Fig. 10. Distribution of thickness on the parts: *a*) box-shaped rotated element (maximum thickness reduction 39%); *b*) cylindrical rotated element with straight segments (maximum thickness reduction 53.7%).

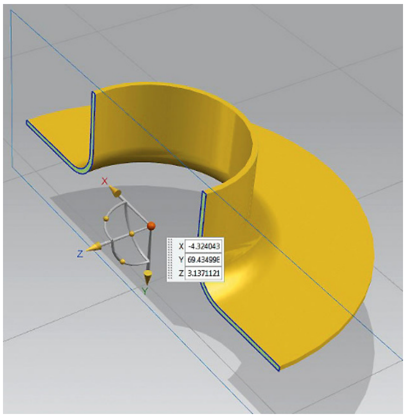

Fig. 11. Cylindrical part with a flat flange.

connection with the tension that the blank undergoes during its initial sliding over the conical surface of the fixture and during its fitting into a fixture of smaller diameter.

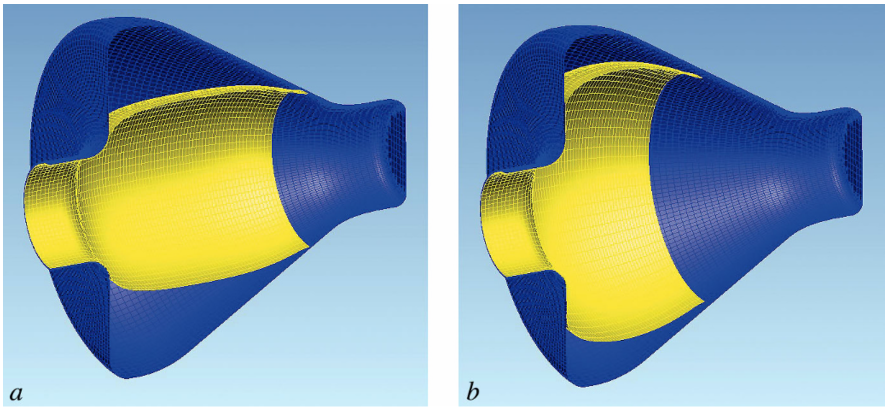

Fig. 12. Results from modeling the process of forming with a sliding edge over a fixture with a conical surface: *a*) decrease in the area of contact between the edge of the semifinished product and the fixture in the sliding zone; *b*) loss of contact between the edge of the semifinished product and the fixture and buckling of the part.

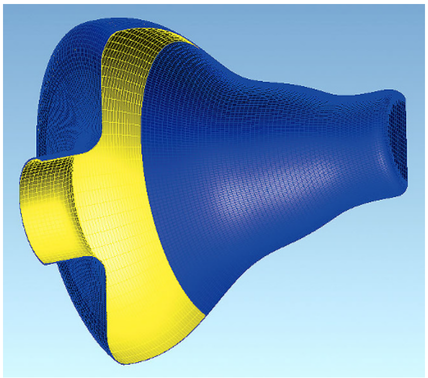

Fig. 13. Results from modeling the process of forming with a sliding edge over a fixture with an integrally concave surface.

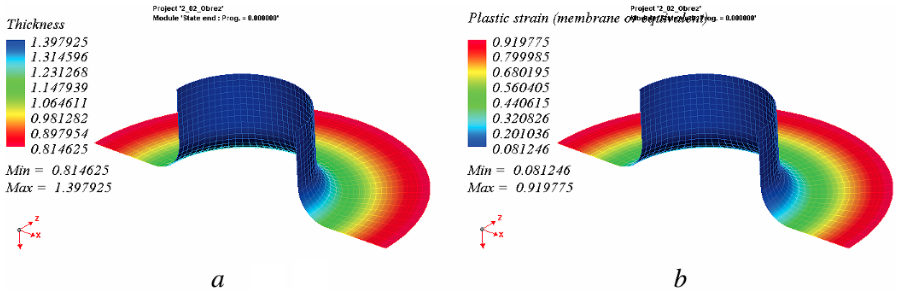

Fig. 14. Thickness reduction and degree of deformation of the part: *a*) thickness reduction of 45.7%; *b*) maximum strain 92%.

The corrugation can be alleviated by decreasing the surface area of the fixture in the rotation zone. We performed a modeling for two variants that involved increasing the area of the fixture in the rotation zone to form a rotated element with a box-like shape, instead of a cylindrical rotated element or such an element with straight sections.

Figure 9*a* shows the results obtained by modeling the PTF process performed so as to obtain a box-shaped rotated element. Figure 9*b* shows the results obtained in forming the cylindrical part of the rotated element with straight segments.

Figure 10 shows the thickness distribution on parts obtained by modeling the pneumothermal forming of a rotated part with a sliding edge.

Thus, the use of the technology that employs a semifinished product with a sliding edge can produce a rotated element of more complex form or allow the addition of reinforcing elements to the surface of revolution. This enhances the stiffness and strength of the part's structure at the necessary locations and in the necessary directions.

Example 3. Tubular part with a flat flange (Fig. 11).

This part will be used to illustrate the feasibility of obtaining a flat flange on a tube by sliding-edge technology.

A fixture with a conical part in the edge-sliding zone (analogous to example 1) was created to model the process. We modeled the formation of the part from a tubular semifinished product with a diameter of 52 mm and a thickness of 1.5 mm. The semifinished product was made of alloy OT4 and was shaped by pneumothermal forming in the superplastic regime.

The modeling showed (Fig. 12) that the area over which the semifinished product contacts the fixture (Fig. 12*a*) decreases substantially during the movement of the edge. This causes the edge to separate from the surface of fixture (Fig. 12*b*), and the semifinished product then buckles. Thus, it was senseless to continue modeling the process and the modeling operation was ended.

The conical surface of the fixture was replaced by an integrally concave surface to prevent loss of contact with the semifinished product. Modeling the forming operation with the concave surface (Fig. 13) showed that the edge did not separate from the fixture. This makes it possible to obtain a part having the desired final shape.

Figure 14 shows the thickness and strain distributions obtained for a part by modeling the operation of forming in an integral fixture in the edge-sliding zone. The deformability of the material was not exceeded.

The results obtained by modeling several variants for forming tubular parts lead to the conclusion that use of the technology in which a tubular semifinished product is shaped by employing a sliding edge makes it possible to solve a number of problems:

1) it decreases the reduction in the thickness of the semifinished product;
2) it reduces strain; and
3) it makes it possible to obtain parts with complex structural elements.

The use of this technology broadens the possibilities for forming tubular semifinished products in the superplastic regime while reducing strain and thickness reduction compared to the classic forming method.

Patent Application No. 2015144617 has been submitted for the above-described technology for forming tubular semifinished products with a sliding edge.

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