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Modeling the process of straightening low-stiff cylindrical parts by cross-rolling with smooth plates

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Abstract. To restore the shape of curved low-stiff cylindrical parts such as shafts and axles, the process of straightening by transverse bending is considered with subsequent hardening by the method of surface plastic deformation based on the transverse rolling of the cylindrical part with flat plates. The stress states of parts during editing are determined using the Ansys Workbench software package. The results of the distribution of the intensity of operating voltages and residual stresses over the cross section of the cylinder, depending on the absolute compression, are presented. The process in question can be implemented without the use of environmentally hazardous lubricating cooling technological means, which makes it possible to attribute it in the future to one of the types of green mechanical processing technologies.

1. Modeling the editing process in Ansys Workbench

Finite element modeling of the straightening process. The influence of the main parameters of the straightening process on the residual stresses in cylindrical parts was investigated by FEM using the ANSYS program [1], intended for mathematical modeling of various physical processes. Modeling the process of editing in the Ansys program allows you to determine the stress-strain state of the workpiece, which is necessary when developing the optimal process.

To determine the stress state in the deformation zone and residual stresses in the straightened parts, a finite element model is constructed in the form of a cylinder and two plates in the Ansys Workbench program (figure 1).

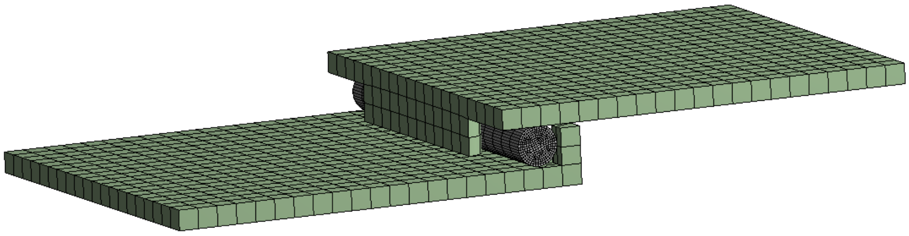

Figure 1. Finite element model of the editing process.

Simulation parameters: The blank is a cylinder with a diameter of 10 mm, a length of 200 mm with a deflection of 0.5 mm from steel St45 (yield strength σ_T = 360 MPa and elastic modulus E = 2 * 10^5 MPa); working plates with dimensions of 5x205x205 mm are considered absolutely rigid. The finite element form is a hexahedron, a thickening of 9030 elements, 40620 knots; coefficient of friction between the workpiece and plates μ = 0.15; boundary conditions: rigid fixation of the bottom plate. In [2], for the transverse rolling of a workpiece with a diameter of D = 10 mm, the maximum value of absolute compression ΔH = 0.43 mm was taken. According to experimental data [2], in practice, to straighten a cylinder with a diameter of D = 10 mm with a deflection of 0.5 mm, the total deflection will be equal to 2.65 mm.

Processing modes: the upper plate moves to the right 2.65 mm (total deflection is 2.65 mm), then the initial position of the plate is unloaded and straightened in the direction of the workpiece. Then it moves down by the value of absolute compression ΔH (ΔH = 0.05; 0.1; 0.2; 0.3; 0.4 mm are used in the work). Next, the top plate moves to the left by 62.83 mm (the workpiece is rotated 1 turn) and moves up by 1 mm (unloading).

2. Calculation results

The dependence of the intensity of operating stresses arising during cross-rolling, on the absolute compression ΔH is shown in figure 2. In the deformation zone, the intensity of the operating stresses increases rapidly with increasing ΔH to 0.07 mm, reaching 410 MPa, and then slightly increasing with increasing ΔH to 0.25 mm. When the value of ΔH is less than 0.05 mm, the working stresses are less than the yield strength (360 MPa) and therefore only elastic deformation is expected in this case. When the value of ΔH is greater than 0.25 mm, the working stresses are greater than the tensile strength (600 MPa) and therefore, under such processing conditions, the material may be destroyed. Thus, the rational value of the absolute compression is in the range ΔH = 0.07-0.20 mm.

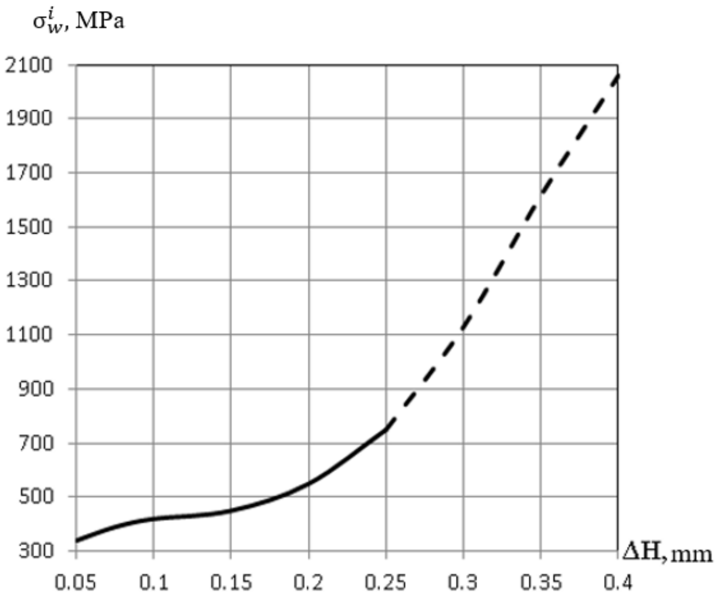

Figure 2. The dependence of the intensity of the working voltage of the absolute compression.

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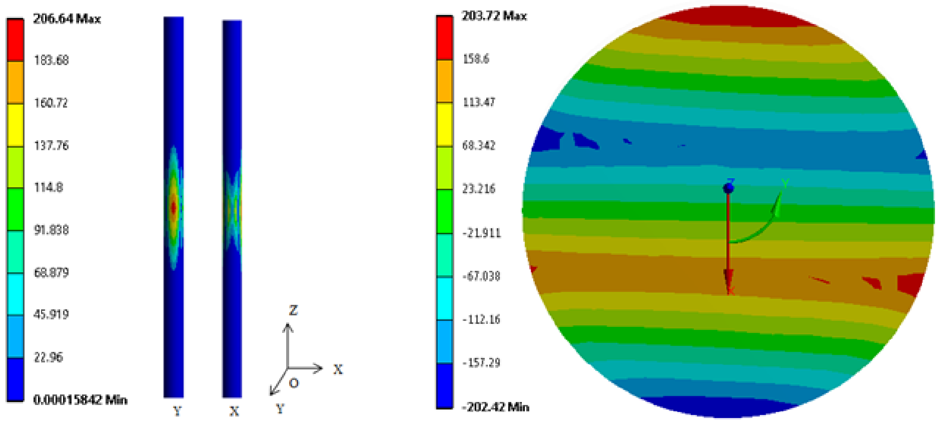
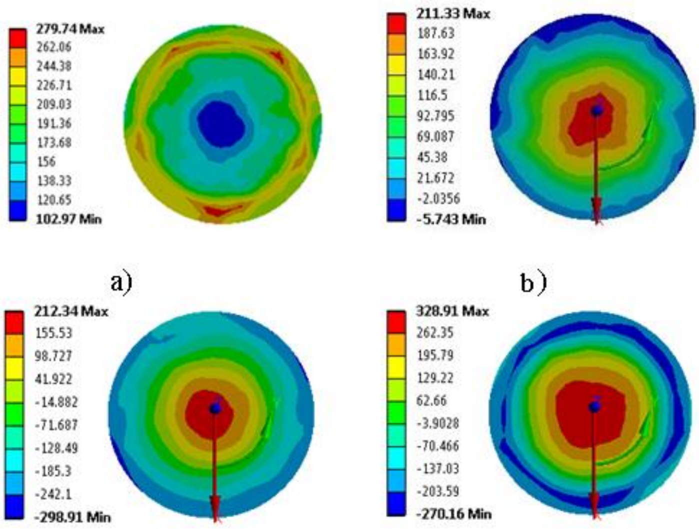
Residual stresses after alignment of parts by transverse bending are shown in figure 3. After straightening by transverse bending, non-equilibrium stresses are formed over the entire volume of the workpiece (see figure 3), therefore, over time, the shape of the part may become distorted again. To equalize the stress state of low-stiff cylindrical parts, it is proposed to additionally process workpieces by means of surface plastic deformation based on transverse running in with smooth plates.



a) b)

Figure 3. Residual stresses after straightening parts in a transverse bend: a is the intensity of residual stresses, b is the axial residual stresses in the cross section (in the middle of the shaft).

In figure 4 shows the residual stresses after cross-rolling with the absolute compression $\Delta H = 0.15$ mm [3, 4, 5]. As a result of the calculations, it was established that after cross-rolling with flat plates, equilibrium residual stresses are formed both along the length and across the cross-section of the workpiece. From figure 4 it follows that in the center of the cross section of the workpiece residual stresses are tensile. The outer layers of the workpiece are deformed in thickness to a greater extent than the inner [6, 7]. By reducing the thickness of the deformation, the perimeter of the outer layers tends to increase and, therefore, they experience a desire to detach from the shaft core. Therefore, tensile radial stresses arise, maximum at the center and equal to zero at the periphery [8, 9]. Tangential stresses are balanced by radial, and axial stresses are balanced by each other.



c) d)

Figure 4. Fields of intensity distribution and components of the residual stress tensor after straightening by rolling the smooth plates: a - the intensity of the residual stresses; b - radial stress; c - tangential stress; d - axial stress.

3. Conclusions

- When straightening cylindrical parts by transverse bending, non-equilibrium stresses are formed over the entire volume of the workpiece and over time the shape of the part may again become distorted. Therefore, after performing this process, it is proposed to additionally harden the workpieces by the method of surface plastic deformation based on transverse running-in with flat plates.
- For straightening by running in with flat plates it is necessary to choose a rational amount of compression in order to exclude the possibility of material destruction. The optimal value of the absolute compression is in the range ΔH = 0.07–0.20 mm.
- After straightening by cross-running with smooth plates, equilibrium residual stresses were obtained along the length and cross-section of the workpiece. At the center of the cross section, the residual stresses are tensile and on the surface are compressive.

Acknowledgements
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