Stand for optimization of thermo-force processing of shafts

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Abstract. The article discusses the design of the stand for the diagnosis and determination of the optimal modes of thermo-force processing (TFP) of light-hard long shaft-type parts. The stand is equipped with an automatic control system (ACS) for heating, cooling and axial plastic deformation. ACS includes three control loops. The functional scheme of the stand and its operation algorithm are described.

1. Introduction
The analysis of the requirements for the quality of processing of light-hard shafts showed that the highest requirements are placed on the operational accuracy of the form and radial runout. The dominant factor in the formation of shaft error is the warping of the shaft as a result of uneven distribution of residual stresses [1-15]. Simulation of the operation of thermo-force processing (TFP) and analytical studies [16-21] showed that the magnitude of deformations of light-hard shaft-type parts can be determined even at the stage of development of the technological process and after that can be determined appropriate minimum processing allowances [22-24].

Purpose. Development of an experimental stand for the diagnosis and management of thermo-force processing. The technical result is to increase the stability of the size and shape of light-hard shaft-type shafts by eliminating directivity and minimizing the level of axial residual stresses.

2. Optimization of thermo-force processing modes and the scheme of the experimental stand
The difficulty of controlling of the process of TFP by axial stretching is that the physical and mechanical properties of the material of the shafts are so diverse that it is simply impossible to find a single control law. The task is to develop a stand that would allow experimentally to find the dependencies of the uniform distribution of volume plastic deformation on temperature, speed and strain value over the entire length of the sample under study. The temperature regime must correspond to the tempering technology for this metal. The stand is equipped with an automatic control system and diagnostics. A required condition for studies of TFP is the choice of samples from one batch of rolled products.
The stand for diagnostics and selection of the optimal control of the TFP for light-hard axisymmetric parts includes a slipway 1, an electric heater 2. The heater is connected to a DC source 3 and fixed on the slipway. As a result, they form a heating circuit for sample 4 and witness-sample 5 (Figure 1). Thermocouples 6 are buried into the body of the sample-witness. The output signal from temperature sensors 6 is fed to the input of amplifier 7, and the output of amplifier 7 is connected to control unit 8. Blocks 7 and 8 form a heating and temperature diagnostic circuit of the sample-witness in length and depth.

Both samples 4 and 5 are connected to grippers 9 by means of a threaded connection. This allows for repeated studies to use one sample-witness 5. Both samples are installed in covers 10 of slipway and fixed using spherical washers 11. Insulation of grippers 9 from samples is done with gaskets 12 installed at the ends of the holes of grips 9. Insulation of the slipway 1 from frame 13 is done by using thermal insulation 14, which is fixed on the stocks. The assembled slipway is mounted into the frame 13, which is rigidly fixed on the foundation shown conventionally. The outflow of heat through the cover 10 is prevented by insulating pads 15.

The thinning of the diameter of the sample-witness 5 is controlled by the probes 16 passing through the frame 13 and the slipway 1 until contact with the sample-witness 5. The ends of the probes 16 are installed with a gap with linear displacement sensors 17 and are spring-loaded relative to the frame 13. This allows to monitor the thinning of the sample-witness. The output of the linear displacement sensors 17 is connected to the analog-to-digital converter 18. The output of the converter 18 is connected to the input of the control unit 8. These units form a circuit for diagnosing the uniformity of plastic deformations along the length of the sample.

Figure 1. Functional diagram of the experimental stand
The linear displacements of the total axial deformations of the sample sensor 19 is fixed on the foundation, as on the measuring base. The output signal of the sensor 19 through the amplifier 20 and the analog-to-digital converter 21 is fed to the input of the control unit 8. These blocks form a diagnostic loop. During of controlling the relative deformation, the axial force loop is included in the work. This circuit includes blocks: a torque unit 22, a force sensor 23, an amplifier 24, an analog-to-digital converter 25. The output signal of an analog-to-digital converter 25 is fed to the input of the control unit 8, which controls the operation of an adjustable electro-hydraulic axial deformation 26.

The experimental stand for diagnostics and control of processing of hard-core axisymmetric parts consists of a slipway with covers and clamps of two samples and a heating element. The sample-witness and the studied sample are installed in the covers of the slipway with two holes for the grips with twisted spherical nuts. The ends of the grips are made with internal thread. Insulating gaskets are installed between the ends of the grips and samples as well as between the covers of the slipway and the heating chamber.

Sensors for gauging diameters include: probes, compression springs, linear displacement transducers and amplifiers. Probes are made of a material with a minimal coefficient of expansion (for example, ceramic). The automatic control system (ACS) includes temperature sensors, linear displacement-thinning diameter sensors and a length sensor for a sample-witness of a dynamometer assembly. Sensors are included in the control circuit. Temperature sensors are embedded into the body of the sample-witness. The length sensor of the sample-witness of the torque unit is installed on the foundation.

The ACS contains three control loops. The first loop provides control of the magnitude and speed of the longitudinal strain. The second loop provides temperature control. The third loop provides control of thinning and uniform plastic deformation. Each control loop contains a sensor, an amplifier, an analog-to-digital converter, a control unit, and a drive.

Monitoring the thinning zones of a witness sample makes it possible to estimate the uniformity of relative deformations during heating and cooling, under compression and tension. This is necessary to estimate the level of residual stresses created in magnitude and direction.

The choice of the number of zones of control over the change in the diameter of the sample-witness is necessary to estimate the magnitude of the uniform relative deformation. Determining the deviation of the total strain of the sample-witness is necessary to assess the temperature mode of exposure of the material of the tested sample. Heat-insulating gaskets on the slipway and in the grips provide stability and uniformity of temperature in the furnace and minimize the leakage of heat through the grips. The controlled power source of the heating element allows controlling the rate of heating and cooling.

The probes of the primary transducers (sensors) allow measuring the thinning of the diameters of the sample witness in real time as a function of temperature and the magnitude of the total axial elastoplastic deformation of the tested sample. The system of automatic diagnostics improves the productivity of research and the accuracy of the obtained measurements of the physical-mechanical parameters of the material under study. Linear displacement sensors and an elastoplastic deformation amplifier determine the magnitude of deformations from axial forces in real-time modes.

Control loops implement a program embedded in the control unit. These control loops provide specified time and heating rate, axial strain values, strain rates, and the required axial forces. The deformation of the sample at the first stage is necessary for the initialization of plastic processes in the metal, that is, the formation and movement of dislocations, displacement and rotation of the grains. Heating of the samples is necessary to reduce the deformation effort by reducing the yield strength of the material of the processed samples. Determination of the deviation of the magnitude of the deformation is necessary to set the temperature mode of exposure to the samples in order to equalize the deformation. Uniform dumping of axial forces in the process of cooling the samples is necessary for the formation of a uniform distribution of residual stresses in the finished products. The electric-hydraulic drive expands technological capabilities due to the smooth adjustment of the applied pressure. Temperature control is an effective, simple and reliable means of controlling the yield strength of a material. The automatic control system increases the processing efficiency due to the
rapid change of the technological parameters of the deformation process. Control loops set and implement the necessary values of axial deformation, strain rate and temperature effects.

The algorithm of the experimental stand is carried out in the following sequence. A sample-witness with caulked thermocouples and a tested sample with grips attached along the contours of the samples are placed in the heating chamber of the furnace. Next, through the holes in the slipway, the ends of the thermocouples are taken out of the frame and connected to the temperature control loop. Next, a lids with spherical washers are inserted on both sides of the slipway, the samples are fixed inside the heating chamber. Then contact the probes of the linear displacement sensors and the outer surface of the sample-witness. The samples are heated to tempering temperature and the tensile force is found as a function of temperature.

Zones of weak dependence of deformation forces on temperature are evaluated. Determine the zones of plastic deformation, when the axial force has little effect on plastic deformation. Using the found zones of weak dependence of the deformation on the axial force and temperature, the uniformity of plastic deformation of the sample under study is estimated. According to the obtained dependences, the mode of stretching of the samples for axial deformation is assigned.

The amount of deformation is assigned on the basis of an assessment of the uniformity of plastic deformations, that is manifested in thinning of the diameters of the witness sample in the installation zones of the probes. Then the process goes into cooling and unloading mode. The unloading of the axial force passes automatically, the force decreases in proportion to the deformation of the compression of the samples until full unloading. At both stages of controlled deformation, heating and cooling, there is no incompatibility of residual stresses and, therefore, ensures the stability of the geometric parameters of finished products.

3. Conclusions
Uniform plastic deformation during heating and axial unloading during cooling is proportional to the magnitude of the compression deformation and ensures a minimum of residual stresses and a uniform distribution along the length. This ensures the operational accuracy of the finished product with minimal loss of electricity and maximum performance of thermo-force processing.

The system of automatic diagnostics and control of axial deformation improves the research performance of the sample material and allows to find the optimal processing parameters.

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