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USE OF RESOURCE-SAVING TECHNOLOGIES IN FABRICATION AND RESTORATION OF STEEL BUSHING-TYPE COMPONENTS VIA HOT PLASTIC DEFORMATION

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ABSTRACT

The article substantiates the expediency of applying the foundations of resource saving in the development of innovative technologies for producing of machine billets hot die forging from worn machine components for the subsequent manufacture of them of new parts in the industrial conditions. Particular emphasis is placed on technologies that provide minimal impact to the environment based on the developed methods of metal processing. The optimal combinations of basic parameters of the process of introducing resource-saving technologies in the repair and maintenance operations are proposed. As an example, the article substantiates possibility of carrying out the process of shaping long tubular forgings from extremely worn thick-walled bushings.

Introduction

At present time almost a quarter of working places worldwide is covered by different industrial branches, including machine-building, while total employment makes 650 mln people. Permanent increase of production facilities leads to deterioration of ecological state in different countries and the level of pollution will continue to rise.

Industrial sector of the economics is based on consumption of both renewable resources (water, wind and sun energy etc.) and non-renewable ones (metals, ores etc.). The processes of metal products manufacture are accompanied by increase of CO_2 emissions; this industry is also characterized by the fact that power expenses are the main expenditures and have significant effect on the cost of manufactured products.

Thereby metallurgical and machine-building enterprises should meet the requirements of different standards (including ISO 14000) to decrease power expenses and to provide competitiveness of manufactured products [1–4].

In this connection, resource-saving should be one of the main development directions of industrial enterprises. According to the balance of ferrous metals in the industrial economical sector and agrarian complex, forming during recent years, about 12% of metal products are used for repair, maintenance and restoration operations. Appr. 60% of them is aimed on replacement of the mechanical components of machines that worked out their resource or lost their working capacities, while 30% are used for recycling and secondary processing; the rest metal is lost completely and irretrievably.

Fabrication of steel components is characterized by the main problems connected with high power consumption, low precision of manufacturing process, large amount of wastes and emissions.

The most part of energy used in manufacturing technologies is generated via thermal processes, while 60–80% of resources in global machine-building is accounting for wastes and emissions, what makes about USD 250 bln in financial equivalent [5–8].

At present time the most part of worn metal-consuming steel components with worked-out resource are subjected to energy-intensive remelting accompanied by burning of alloying elements. To remelt 1000 tons of worn metal components, it is required to use 20 t of conditional fuel, 50 t of oxygen, 1000 t of water and 10 mln kWt·h of electric power, while metal losses will make 10% and 120 t of carbon dioxide will be emitted in the atmosphere [9].

Utilization of worn components and fabrication of new ones instead of them, using round bars or flat sheets, finalizes in metal losses with chips within 10–25%. It should be also taken into account that the complete cycle of manufacturing initial shaped rolled products includes such labour-intensive and ecologically unfavourable processes as mineral exploration, development and reclamation of mineral deposits, mining and mineral processing, iron and steel making, ladle treatment and rolling of steel products, their chemical-thermal treatment and mechanical processing, as well as transportation.

Processing methods of ferrous metals

Theoretical substantiation of the suggested technology was based on usage of variation method; its essence concludes in choosing the "suitable" functions for mathematical description of the features of metal transfer during plastic deformation and for evaluation of influence degree of separate technological parameters on the process efficiency.

Upsetting process simulation was conducted on lead models. Deformation force, heating temperature and deformation rate at the fixed deformation degree were chosen as the factors having effect on power-intensity of the technological process. The massif of factor experiment results was processed used the standard program MarhCAD PLUS 8.0.

Measurements of geometrical parameters of bushings were conducted for diameters and lengths that are the main constructive dimensions and mostly characterize wear. The facts of buckling, erosions and cracks were revealed visually.

Microstructure observations were conducted on flat polished sections using MIM-8M microscope.

The technique of step-by-step measurements of deformation forces is based on indirect pressure measurement in the work cylinder of punch hydraulic drive using pressure load cell incorporated in EKM-2U600 manometer and resistance strain gauges collected in a half-bridge scheme. Strain-gauge amplifier was used for strengthening of signals from a sensor. The values of controlled parameters were recorded by 4-channel self-recording equipment allowing to fix the processes with frequency up to 100 Hz.

Obtained results

The essence of model buildings during choice of optimal combination of parameters of resource-saving technologies concludes in determination of the optimal relation between physical, structural and mechanical properties of components quality, as well as parameters of their service life and operating efficiency within technological process [10].

Minimization of labour, material and power expenses is the main goal of optimization of the technological process of components restoration. The goal function in this case can be presented as

$$f(c) = \sum_{i=1}^{n} \left(N_i/k_{di}\right)\left(T_{Hi}C_{\text{Ч}i} + M_iC_{Mi} + \text{Э}_iC_{\text{Э}i} + K_i\right) \to \min, \quad (1)$$

where N_i — annual restoration / fabrication program, pieces; k_{di} — service fife ratio; T_{Hi} — time regulation, man-hour; M_i — metal capacity of the technology, kg; Э_i — process power capacity, kWt·h.

Specific capital intensity of the process K_i takes into account the effect of such economic parameters as balanced cost of equipment, cost of manufacture of technological auxiliaries, indirect costs on efficiency of the technology for fabrication of new components instead of worn ones. It is considered as parameter of financial correspondence of the developed technology to the current economical situation. In this case the following inequation should be kept:

$$\sum_{i=1}^{n} K_iN_i \le S_k, \quad (2)$$

where S_k — financial resources of the enterprise, rub.

At the same time renovating enterprise should have modern equipment as well as labour, material, power and financial resources. Metal losses and ecological effect on the environment should be minimized.

$C_{\text{Ч}i}$ in the formula (1) is hourly wage rate, rub/h; additionally C_{Mi} is cost of repair materials, rub/kg and $C_{\text{Э}i}$ is electric power cost, rub/ kWt·h.

Realization of this model for concrete conditions of putting into practice allows to intensify use of renovating technologies for fabrication of metal-intensive resource-definite components from worn ones. The method of this fabrication is similar to the method previously used for their initial fabrication and meeting the requirements to quality service life, resource saving and production efficiency with substantial lowering of the part of material losses owing to partial exclusion of semi-fabricating operations from technological route.

In the case of secondary use of such metal-intensive components as ultimately worn and recycled long-size thick-walled bushings that were manufactured via die forging, forging, rolling or extrusion, it is recommended to use the metal forming method based on metal softening as a result of heating up to plastic deformation temperature and forced metal redistribution from idle edge surfaces to worn areas, with its transfer to allowance area for mechanical processing of defected layer. The proposed method is maximally close to conventional fabrication technology, what allows to save wear resistance and service life parameters of a forging manufactured from recycled component at the level typical for a new similar billet.

Hollow cylinder components — bushings of assembled sections of industrial tractor caterpillars — were chosen as an example illustrating possibilities of the developed method. These bushings have low level of complex availability, they are rejected as a result of non-uniform wear in external and internal diameters and they are subjected to unjustified recycling.

The restriction connected with necessity of obtaining minimal required and uniform deviations is one of the features of plastic forming of worn bushings. Additionally, the threat of losing longitudinal stability and clamps forming arises in the process of hot upsetting of cylinder components at relatively large billet length/diameter relation [11].

Analysis of metal transfer kinematics was based on variation method; its essence concludes in choosing the "suitable" function for mathematical description of metal transfer features during plastic deformation [12].

It is important to determine power and force parameters of metal forming process for forgings from rejected components. For example, the process of bushing upsetting can be conditionally divided by 4 stages (**Fig. 1**).

Formula for determination of deformation force at the 1st stage is as follows:

$$P_1 = \frac{\sigma_{To}(1+\beta\Delta h_i)Fh}{h-\Delta h_i}, \quad (3)$$

where Δh_i — value of deformation run, mm; β — coefficient of material resistance increase, mm^{-1}.

Force at the 2nd upsetting stage will be equal to:

$$P_2 = P_{Tor} + P_{Tr} = \rho_o \pi (R_{con}^2 - R_n^2) + 2\pi R_{con} \frac{h}{2} \mu q_r, \quad (4)$$

where μ — friction coefficient; q_r — pressure on die walls, MPa; ρ_o — specific load on edge plane, MPa.

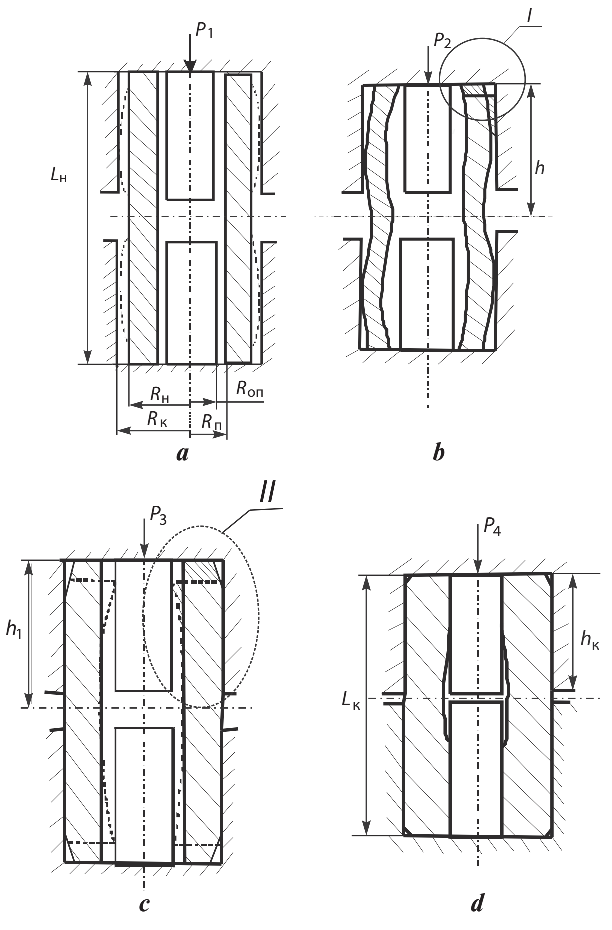

Fig. 1. Hot upsetting stages for a bushing-type component: *a* — free uniform upsetting until touching die impression walls by heated metal; *b* — filling of die spaces from external surface side of deformed bushing; *c* — filling of die spaces around plug during hole forming; *d* — final stage of filling so-called "dead" areas

Force at the 3rd upsetting stage is determined via the following formula:

$$P_3 = P_{Tor} + P_{Tr.Tor} + P_{Tr.Bok}, \quad (5)$$

Where $P_{Tor} = \rho_o \pi (R_{con}^2 + R_{opr}^2)$; (6)

$$P_{Tr.Tor} = \mu_T \sigma_T \pi (R_{con}^2 - R_{opr}^2); \quad (7)$$

$$P_{Tr.Bok} = 2\pi R_{con} \left(\frac{h_1}{2} + \Delta h \right) \mu q_r. \quad (8)$$

At the 4th stage the final forming occurs.

$$P_4 = P_{Tor} + P_{Tr.Con} + P_{Tr.Opr}, \quad (9)$$

where P_{Tor} is determined via the formula (6),

$$P_{Tr.Con} = 2\pi R_{con} h_k \mu q_r; \quad (10)$$

$$P_{Tr.Opr} = 2\pi R_{opr} h_k \mu q'_r, \quad (11)$$

where q'_r — pressure on plug.

The diagram of relation between variation of deformation force and upsetting value is built on the base of the results of step-by-step power and force calculations, applying to the process of hot metal forming of worn bushings V34021 of assembled section of paddy combine SKGD-6R (**Fig. 2**).

The revealed regularities display the non-linear character of deformation force variation depending on deformation degree during forming of thick-walled long-size bushings via upsetting. The range of deformation force variation depending on upsetting value is established on the base of the results of step-by-step power force calculations. This range is applied to the process of hot metal forming of forgings from worn bushings of assembled caterpillar section and is in the range from 60 to 315 kN.

Graphical analytic processing of curves from a self-recording device switched to load cell mounted on elastic element of manometer hydraulic press through strain-gauge amplifier, was conducted with usage of calibration chart. 10% deviation between experimental data and theoretical force calculations was obtained on the base

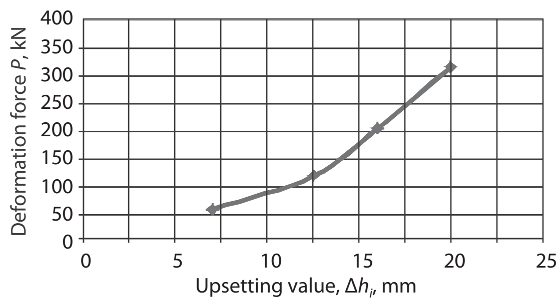

Fig. 2. Relation between deformation force and upsetting value for a bushing-type cylinder component with size diam. 28/45 mm and length 112 mm

of recorded diagrams of pressure variation in working cavities of force hydraulic cylinders of drive of deforming punches. This deviation is considered as allowable for metal forming processes and confirms reliability of theoretical issues.

Choosing of technical parameters of forging and pressing equipment was realized on the base of presented force calculations.

The developed technology allows to decrease labour intensity of production process due to reuse of material of worn steel components. Putting into practice of the developed method makes it possible to solve partly the problem of recycling of worn components at repair and maintenance enterprises of agro-industrial complex.

Metal saving ($E_{м}$) during repair of these metal-intensive components is forming owing to difference between irreversible metal losses forming in manufacture of new components from worn ones.

$$E_{м} = M_r(1 - K_l^{met} - K_l^{mach}) - M_p, \qquad (12)$$

where M_r — mass of components ready for reuse as billets, kg; M_p — metal consumption in manufacture of new components from worn ones, kg; K_l^{met}, K_l^{mach} — coefficients of metal losses in metallurgical and machine-building production respectively.

Taking into account restoration program (N_e = 10,000 pieces) and mass of each component, total saving of structural manganese-alloyed steel 20G was determined and made 30 t.

Use of the proposed technical solution allows to form additional production facilities in Russia for secondary processing of worn steel machine components [13–15].

Conclusions

The suggested resource-saving technology is based on hot plastic deformation of ultimately worn metal-intensive components; it allows to obtain forged billets for consequent fabrication of near net shape auxiliary parts for combines, tractors, automobiles and other machines using conventional industrial technologies. The presented technical and economical calculations testify on efficiency of conducted research. It is shown that outing into practice of the developed technological processes will help to solve independently the problem of supplying production facilities with waste parts and billets for their fabrication with benefit for repair and maintenance plants.

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