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Hardening Treatment by Plastic Deformation under Conditions of the Integrated Local Loading of a Deformation Zone

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Abstract

The paper considers the method of hardening treatment by plastic deformation under conditions of the integrated local loading of a deformation zone. The main positions of preparing and carrying out experimental research are adduced, as well as their results are provided. The authors discover the character of hardening process technological parameters influence on producing part mechanical parameters. We establish that the number of processing cycles has more influence on maximum hardening degree, whereas the instrument axial step exerts more influence on maximum depth of hardened zone. The paper presents the mathematical model of the considered process, which proved its adequacy in comparison with the results of experimental studies. It also indicates the directions for further research.

Keywords: Metal treatment under pressure, Integrated local deformation, Hardening curve, Hardening treatment modeling, Microstructure.

INTRODUCTION

Permanent intensification of operating conditions of machine component sand parts imposes high demands on their operational characteristics. At the present time, several ways to solve this problem are possible. On the one hand, to manufacture this or that part, it is possible to use more strong material, however, it involves an unreasonable increase in the product price. On the other hand, it is possible to increase the overall dimensions of a product, however, this is usually impossible due to limitations imposed on the overall dimensions and weight.

Taking the abovementioned into consideration, the most rational way out of this situation is the use of the hardening treatment [1-2]. This will allow increasing the strength characteristics of components and provide the required product dimensions and weight.

When selecting a method of hardening, it is needed to take into account the following initial conditions:

– retention of a product geometric shape and weight;
– achieving the desired degree of hardening;
– ensuring favorable combination of strength and operational parameters of a product;
– minimizing an energy consumption required for ensuring a hardening process.

The purpose of this study is to establish the scientific foundations of numerical modeling of hardening treatment processes by integrated local straining (ILS) with the aim to predict the dependence of mechanical and operational parameters of processed workpieces on the initial parameters of the technological process. The object of study is split-shell bearings.

ILS is a unique method developed by an authoring team on the basis of Orel State University [3-9], which lies in combination in a single process if the global monotonous loading of the entire workpiece material volume and the local alternating load. It should be noted that global loading does not lead to a plastic metal flow, thereby facilitating local straining process intensification.

Objectives of the study:

1. Carrying out experimental studies of integrated local straining;
2. Identifying features of hardening treatment, proceeding under conditions of integrated local loading of the deformation zone;
3. Model development for numerical ILS modelling.

BACKGROUND

In [1-2] the most widespread methods of hardening treatment are considered (Fig. 1). They can be divided into two major groups: methods of surface hardening and methods of volumetric hardening. Considering the disadvantages of the specified groups, it is possible to conclude that the methods of surface hardening are characterized by such disadvantages as: abrupt transition boundary from the hardened zone to non-hardened, significant inter-phase stresses, small hardening depth, large energy consumption for treatment (mainly for the methods connected with thermal, chemical-thermal or electrical effect).

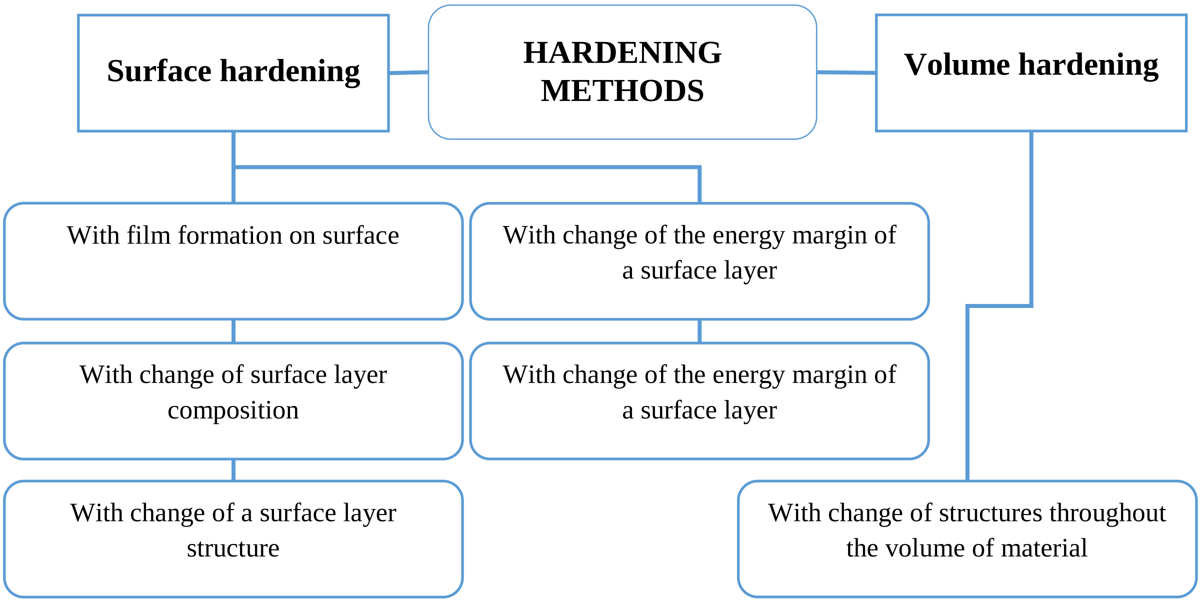


Figure 1: Methods of hardening treatment

Methods of volumetric hardening are characterized by the following disadvantages: hardening of the entire metal volume and, as a consequence, an increase of its fragility; high cash and energy expenditures due to the demand for expensive equipment and, in a case of machining (volumetric plastic straining), loading of the entire metal volume, that leads to a great required treatment forces.

The relevance of the work is explained by the demand of different economy sectors for machine components or construction elements that combine unique mechanical and operating parameters, such as strength and wear resistance. The example of such components is the split-shell bearings, technological manufacturing process of which lies in obtaining a cast billet and subsequent machining followed by applying the hardening antifriction layer on a working surface.

The disadvantages of this method encompass the thinness of the applied coating layer, as indicated by rapid wear and formation of defects inherent to this type of components, such as spalling, tearing-out or galling. As a rule, the only correct solution to the specified problem is application of various hardening treatment methods (see Fig. 1). However, they have the following disadvantages:

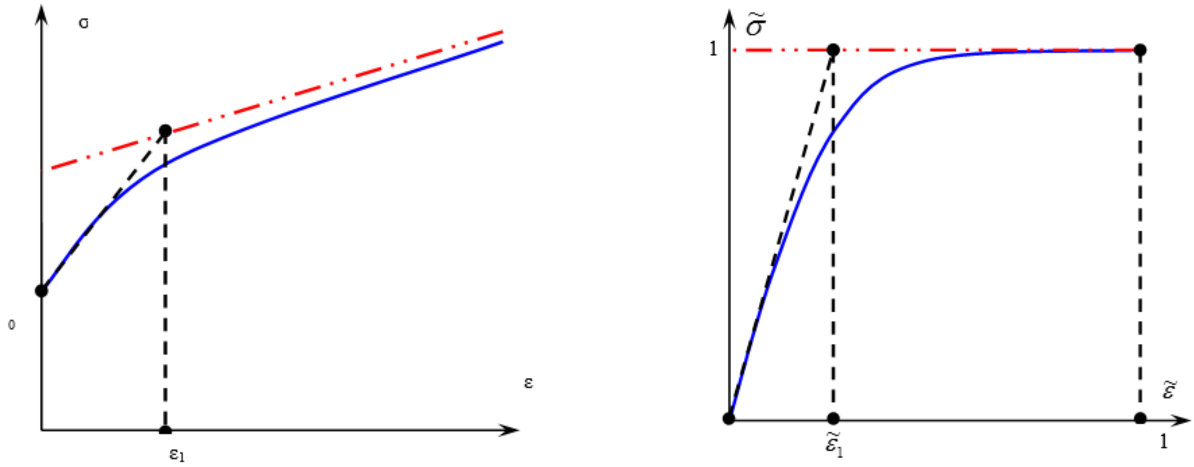
(1) for methods of surface hardening: small thickness of a hardened layer, high inter-phase stresses, lack of gradient in the transition from a hardened to non-hardened zone, large energy expenditures to perform individual types of hardening treatment, for example, thermal treatment or treatment by electrical current effect.

(2) for methods of volumetric hardening: expensive and energy-intensive equipment, as well as hardening of the entire component volume, that leads to its embrittlement.

It is worth noting that for the majority of hardening methods with both volumetric and surface straining, such a disadvantage as violating the workpiece macro-geometry is inherent. A promising direction is the combination of hardening treatment by smoothing and by rolling in a single process, which, in turn, will allow achieving high degrees of strain due to multi-cyclicality of the treatment process.

METHODOLOGY

Within the framework of theoretical study [10-11] such a feature of hardening ILS was revealed, as the complexity of presentation and further use of hardening curve of a material under treatment. Due to that, the method of presenting the hardening curves in the form of NURBS (non-uniform rational B-spline) functions (Fig. 2) is proposed [12-13].



a b

Figure 2: Obtaining the approximated hardening curve
(a – experimental hardening curve; b – reduced hardening curve)

The essence of the method lies in obtaining, on the basis of an experimental hardening curve, NURBS function formula having the general form (1):

$$\mathbf{P}(u)=\frac{\sum_{i=0}^{n} h_i \mathbf{p}_i N_{i,k}(u)}{\sum_{i=0}^{n} h_i N_{i,k}(u)} \qquad (1)$$

$$(0 \le u \le 1)$$

where p_i – poles (characteristic points, to which the curve is bound to) in multidimensional space; h_i – weight factors; $N_{i,k}$ – Bernstein polynomial.

$$N_{i,k}(u)=\frac{(u-t_i)N_{i,k-1}(u)}{t_{i+k-1}-t_i}+\frac{(t_{i+k}-u)N_{i+1,k-1}(u)}{t_{i+k}-t_{i+1}} \text{ at } t_{k-1} \le u \le t_{k+1}, \qquad (2)$$

$$N_{i,1}(u)=\begin{cases}1 \text{ at } t_i \le u \le t_{i+1} \\ 0 \textit{ in the contrary case}\end{cases} \qquad (3)$$

This way of presenting hardening curves contributes to economy of the disk space, as well as makes the computer calculations more convenient and fast. For software implementation of considered process the schematic diagram was developed, which is shown in Fig. 3.

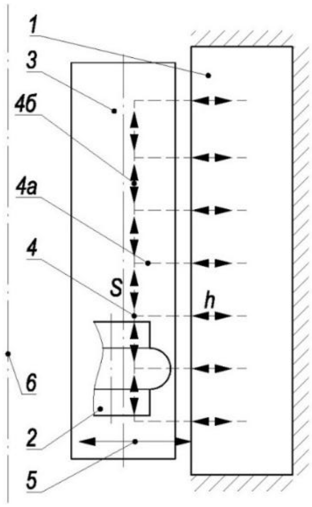


Figure 3: Section A-A of axially symmetric model (1 – workpiece under treatment; 2 – straining roller; 3 – smoothing roller; 4 – straining roller movement trajectory; 4a – trajectory of single-fold introduction of the straining roller for a value h; 4b – trajectory of single displacement of the straining roller in longitudinal direction for feed step value S; 5 – smoothing roller movement trajectory; 6 – axis of symmetry)

Conditionally, the process of hardening roll die forging stamping under conditions of integrated local loading of a deformation zone can be divided into the following stages:

1. Introduction of the straining roller 2 into the workpiece 1 along the path 4a by the value *h*. At that point, the smoothing roller 3 is taken away from the workpiece 1.
2. Taking away the straining roller 2 from the workpiece 1 (path 4a).

3. Smoothing the extruded metal masses by roller 3 moving along the trajectory 5 (roller moves to the level of the initial workpiece surface).
4. Withdrawal of the smoothing roller 3 along the trajectory 5.
5. Displacement of the straining roller 2 in the axial direction along trajectory 4b by feeder step *S*.

Then steps 1–5 are repeated until reaching the edge of the zone under treatment, after that the displacement of the straining roller 2 by the feed step is executed in the opposite direction with repeating steps 1 to 5.

In the course of workpiece treatment by the hardening roll die forging, the largest stresses and strains take place nearby the inner surface, due to that fact to obtain the most reliable picture of the material stress-strain state the composite triangular grid was used, which is denser on the inner surface (Fig. 4). In the rest of layers and in near frontal areas its density is significantly reduced. Such a structure allows reducing machine time spent to perform the necessary calculations without loss of result's quality.

Also, there is no need to simulate the treatment of the entire surface, wherefore a segment of certain length in the middle of a workpiece was subjected to consideration, which also saves time required to perform a calculation, not affecting the quality of the obtained results.

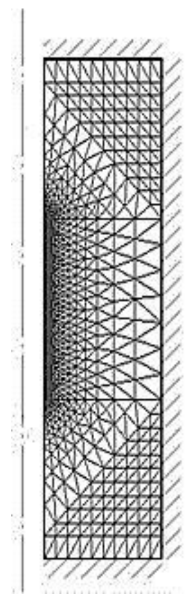


Figure 4: Finite-element grid for ILS research

When carrying out the comparative analysis of experimental research results and mathematical simulation, it was revealed that the maximum deviation of results is not more than 11.8%, which allows evaluating the adequacy of the developed mathematical model within acceptable error intervals.

RESULTS

In accordance with the set objectives there was developed the method of hardening treatment of the inner surface of split-shell bearings (Patent 2462327 RF) (Fig. 5).

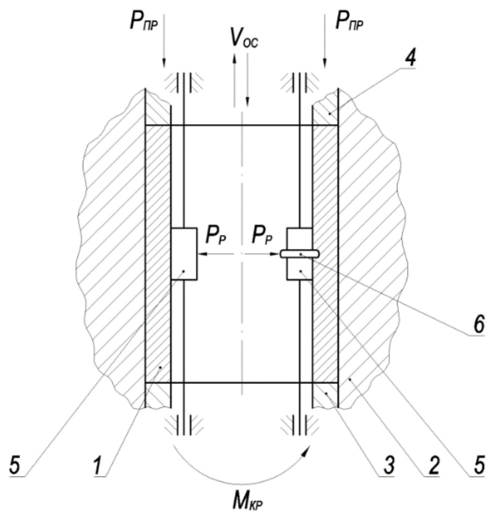


Figure 5: Method of hardening ILS of the inner surface (1 – workpiece; 2 – container; 3 – stop; 4 –hold-down clamp; 5 – roller; 6 – straining bulge)

According to [3], the workpiece 1 is installed into container 2, thereby fixing in the treatment position from radial displacement. Axial limiters are stop 3 and hold-down clamp 4. After that the processing tool is introduced into the workpiece cavity, which includes rollers 5, one or more of which have a straining bulge 6. The rollers are pressed down to workpiece 1 surface with a force of P_p. Then torque $M_{кр}$ is applied to the tool, and movement is imparted with velocity V_{oc}.

In treatment, the local strain zone of dispensing appears in the workpiece near the dispensing band on this training roller. Since the band has a rounded shape, metal distributes to the sides, and there appear axial tensile deformations under conditions of all-round compression caused by:

- normal compression stresses which appear as a result of material compression between the roller 5 having a larger diameter segment 6, and the container;
- tangential compressive stresses conditioned by the resistance to metal plastic outflow as a result of introduction of the straining bulge 6 from the side of non-deformable workpiece layers in the tangential direction;
- axial compressive stresses conditioned by material plastic outflow in axial direction and its obstruction from the side of stop 3, hold-down clamp 4 and non-deformable workpiece layers.

Such stress state contributes to a substantial increase of material plasticity resource, and accumulation of alternating trains at fulfilment of several cycles of reciprocating movements facilitates the grain refinement and formation of gradient from the inner workpiece surface, sub-micro-structure, and in the case of execution of the greater number of cycles – nanostructure of the material nearby the product inner surface, and, as a consequence, hardening which is gradient across the section.

Unlike other wide-spread methods, the aforementioned one has the capability to execute treatment of internal surfaces of hollow axially symmetric workpieces with simultaneous ensuring the initial workpiece geometry intact. For ensuring the described process the conceptual scheme (Fig. 6) and the experimental attachment (Fig. 7) were developed [1-2, 14-18].

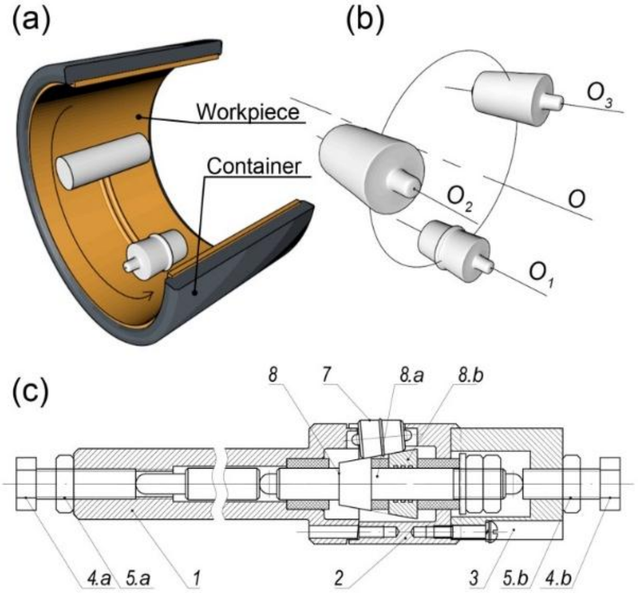


Figure 6: Operation principle (a, b) and internal arrangement organization (c) of internal roll burnisher (1 – shank end; 2 – separator; 3 – hold-down clamp; 4.a, 4.b – adjusting screws; 5.a, 5.b – locknuts; 6 – smooth rollers (position not shown); 7 – strainingroller; 8 – support; 8.a – part of support rotating relative to its axis; 8.b – part of support rotating relative topart 8.a)

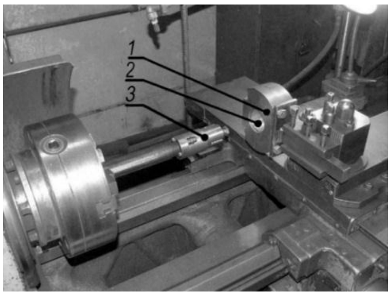


Figure 7: Experimental attachment attreatment position (1 – roller; 2 – workpiece; 3 – container)

Table 1 shows parameters of the technological process implemented when performing the experimental study.

Table 1: Table of technological process parameters

Parameters	Value			
Workpiece				
External diameter *D*, *mm*	70			
Internal diameter *d*, *mm*	50			
Length L, mm	50			
Tool				
Bulgewidth R_{BULGE}, *mm*	1			
Technological process				
Number of tool passes *N*	15	20	25	30
Feedstep $h = x{\cdot}R_{BULGE}$		0.25		
		0.5		
		0.7		
		1		

Table 2 shows measurement results of characteristic geometrical parameters of experimental samples before and after treatment.

Table 2: Change in workpiece geometrical parameters

No.	Internal diameter d, mm	Deviation from circularity, μm
Before treatment		
1	50	10.98
2	50	9.95
3	50	3.02
4	50	7.25
5	50	3.39
6	50	5.71
After treatment		
1	50	18.66
2	50	12.94
3	50	15.79
4	50	11.94
5	50	32.00
6	50	29.71

The presented data show that geometrical parameters selected for control change insignificantly and can be compensated by further mechanical development, therefore, when performing hardening ILS numerical simulation, they can be neglected.

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Measurement results of micro-hardness parameter distribution in the radial direction from the internal surface are presented in Fig. 8. It should be noted that the obtained data point to forming of unique indicators of hardening parameters distribution, unattainable by other methods.

It is worth noting that the micro-hardness parameter value is to the greater extent affected by the number of treatment cycles than the tool axial feed step, and the value of hardened layer thickness – the value of tool axial feed step.

Within this study, the maximum number of hardening cycles was 30, while the value of micro-hardness parameter increased 2...3 fold.

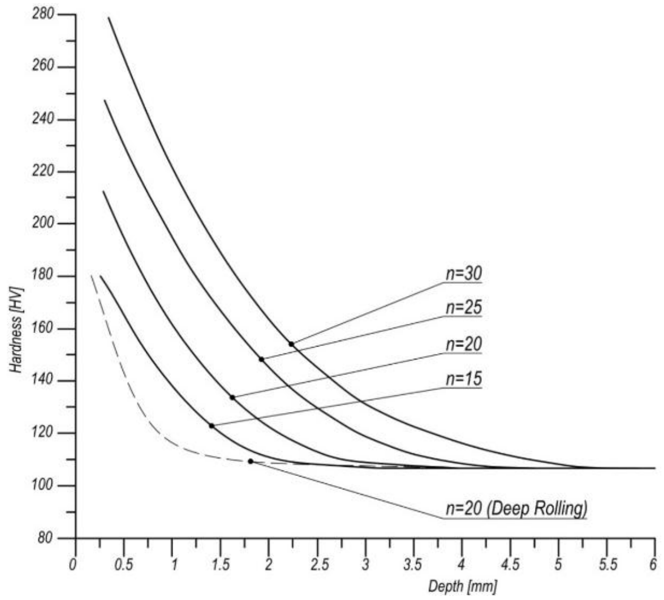

Figure 8: Micro-hardness parameter distribution in the radial direction across the section of studied samples

At that, the visual microscopic analysis of studied samples structure (Fig. 9) confirms the flow of intensive plastic yield processes which contribute to refinement of structural elements and formation of the optimal ratio of operational parameters.

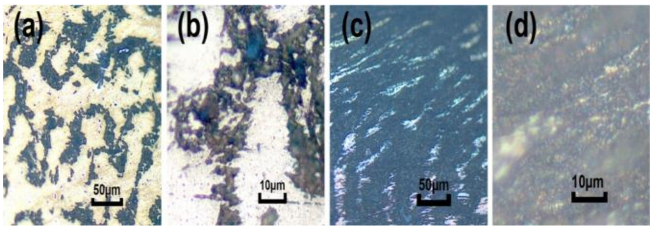

Figure 9: Micro-structure of the near-surface layer of studied samples (*a* and *b* – untreated sample; *c* and *d* – treated sample)

DISCUSSION

As a result of the study carried out, the features of hardening parameter's change depending on the technological process parameters were revealed: the number of treatment cycles impact greatly on the growth of cold work degree than the axial feed step, whereas the axial feed step impacts greatly on the value of hardened area thickness than the number of treatment cycles. It was estimated that in the course of the process of hardening ILS realization the process of intense plastic staining runs, that is evidenced by the formation of structural elements in hardened area within the range of 100–200 nm.

Computer model of the hardening ILS process was developed, which includes an innovative approach to presentation of hardening curves. It showed a good agreement of the simulation results with experimental researches which allowed predetermination of its adequacy.

CONCLUSION

The developed model will allow significant reduction of a designing time of hardening ILS technological processes, what is relevant for the majority of modern industrial economic sectors such as aircraft construction, shipbuilding, automobile production, turbine unit production, etc. This, in turn, will allow the prime cost reduction and increase of its competitiveness. For carrying out further researches, it is planned to accumulate and methodize the simulation data in order to develop the design procedures of hardening ILS technological processes excluding simulation, which will allow reducing the time costs for this type of activity by dozens times.

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