IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Improvement of the working surface resistance of a stamping tool with coating and SSS modeling of the preliminary mechanical activation of the surface layer of the stamp working parts

To cite this article: V P Tabakov *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **866** 012049

Improvement of the working surface resistance of a stamping tool with coating and SSS modeling of the preliminary mechanical activation of the surface layer of the stamp working parts

V P Tabakov[1], V N Kokorin[1], O I Morozov[1], M V Ilyushkin[2], Y A Titov[1] and E L Kornyakov[3]

[1]Ulyanovsk State Technical University, 32 Severny Venets Street, Ulyanovsk, 432027, Russia
[2]JSC Ulyanovsk NIAT, 34 Doctor Mikhailov Street, Ulyanovsk, 432057, Russia
[3]JSC Ulyanovsk Cartridge Plant, 1 Shofyorov Street, Ulyanovsk, 432007, Russia

E-mail: vnkokorin@mail.ru

Abstract. A research technique was developed. The selection of the processed samples (sizes, material, operating conditions) was carried out. The physical and computational model of the process of cold plastic deformation of samples from tool heat-resistant steel X12M was developed. The technique for studying the effect of cold plastic deformation on the adhesive ability of a substrate – coating system is presented.

1. Introduction

The relevance of the study lies in the creation of a new technology for producing wear-resistant coatings on a modified tool working surface, the selection of processing modes and the design of a working tool for sheet, cold volume and hot stamping dies from semi-heat and heat-resistant steels of high viscosity, as well as molds. Currently, surface modification methods are implemented only in the technology of increasing the resistance of the cutting tool (cutters, drills, etc.) and are not effective for increasing the resistance of punch and dies in metal forming processes, where it is necessary to carry out a comprehensive modification of the substrate-coating system. The working tool of dies (punches and dies) works in severe loading conditions: the presence of shock, alternating loads; the presence of features of the friction forces between the processed material and the tool and temperature conditions of processing.

The essence of the proposed technology developed in the Ulyanovsk State Technical University consists in a comprehensive modification of the surface layer: preliminary mechanical activation and deposition of hardening coatings by the ion-plasma method. During its implementation, there is a significant increase in the adhesion of the “substrate-coating” system, a decrease in thermal conductivity and softening of the metal of the stamp surface layer. The observed effect is due to the distortion of the metal crystal lattice, an increase in the density of dislocations during plastic deformation. The use of complex (mechanical activation + hardening coating) surface modification will significantly increase resistance, increase the service life of dies and molds.

2. Research methods

The technology to increase the resistance of the working surfaces of parts of dies and molds made of heat-resistant steels using complex modifications is as follows:

1. Preliminary cold plastic deformation of the machined metal surface is carried out in any traditional way (rolls, impact between the strikers, etc.). At this stage, a favorable texture is formed (macro-, micro-), activation and mechanical hardening (strain hardening) takes place in the area of the working area;
2. The final modification of the surface layer is carried out by applying a wear-resistant multilayer coating to the hardened working surface by ion-plasma spraying.

The main types of materials that can be used in the implementation of the developed technology are a group of heat-resistant and semi-heat-resistant tool steels having a heat resistance of more than 500 °C and retaining their physical and mechanical characteristics at temperatures above 300-400 °C, which makes it possible to use them as a material substrates during coating by ion-plasma coating. The permissible overall dimensions of the samples are usually determined by the dimensions of the working area of the Bulat installation for applying wear-resistant coatings and are 200x200x200 mm.

To increase the efficiency of the adsorption process, in a number of publications by foreign authors it is proposed to use mechanical deformation, which consists in mechanical activation of the metal when implementing the uniaxial compression scheme of a workpiece [1-4]. Based on our experimental work, a physical model was proposed that combines mechanical deformation with the binding energy between the elements of the system under consideration: a substrate (acting as a catalyst) and a coating (acting as a reagent).

It was found that in order to increase the adsorption efficiency, it is necessary to reduce the activation energy in the longitudinal direction of the crystal lattice (its tension), which corresponds to the effect created by uniaxial mechanical compression deformation [1-3].

Figure 1 shows a physical model of the structuring of the substrate-coating system (a fragment of the crystal lattice of the substrate) during complex modification (cold plastic deformation followed by ion-plasma coating), which allows illustrating the increase in the efficiency of the adsorption of particles of the coating material (reagent) onto the substrate.

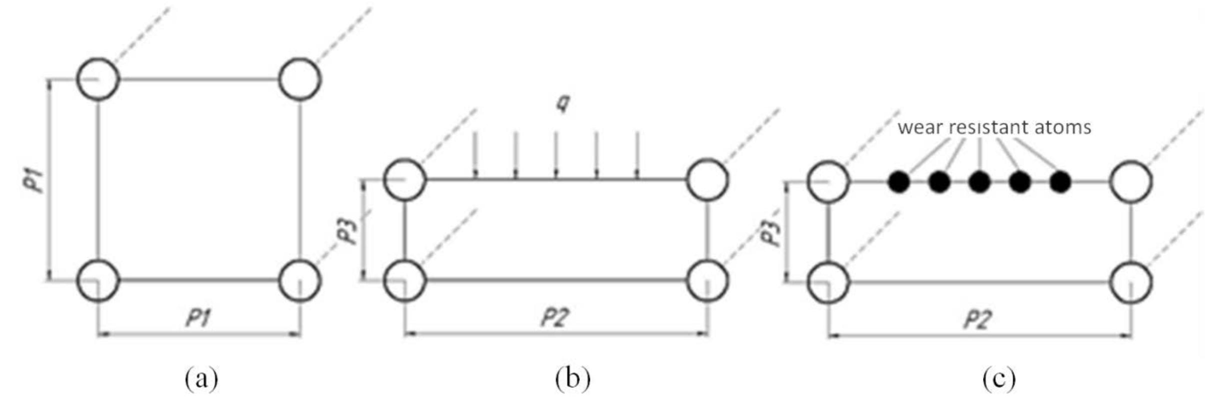


Figure 1. Physical model of the structuring of the "substrate-coating" system with complex modification of the surface layer: a – the original structure; b – deformed structure, – uniaxial compression; c – modified structure of the substrate-coating system.

As was established in the works [1,3] of foreign authors, the arising mechanical stress increases the bonding strength between the elements of the “substrate-coating” system, which is the result of “pulling together” of the atoms of the metal of the substrate at a certain amount of deformation of the surface of the substrate.

In preliminary experimental studies, tool heat-resistant steel X12M GOST 5950-2000 was used as the material of the model and samples for. Based on an analysis of literary sources, the results of mechanical tensile tests of X12M steel were studied and a tensile test diagram was used (maximum tensile strength σ amounted to 1422 MPa, average 1364 MPa).

For a more accurate verification of material parameters when creating the model, the results of A.D. Khvan [8], according to which, according to the results of compression tests on cylindrical specimens for X12M steel, a flow curve was constructed in coordinates to evaluate its mechanical characteristics: stress intensity (σi) - strain intensity (ei).

The experimental tests (sediment of sample-tracks) were carried out on a hydraulic press (nominal press force – 1500 kN), the material of the samples was semi-heat-resistant tool steel X12M, the initial dimensions of the samples were a*b*s0=10x10x10 (mm), the experimental modes are presented in table 1.

Table 1. Modes of experimental studies with uniaxial compression.

No.	Material sample	Initial overall dimension s of the sample			Deformation force F, tf	Pressure deformations R, MPa	Overall dimensions of the deposited samples			The degree of deformation under uniaxial compression ε ,%
		a mm	b mm	S_0, m m			a_1, m m	b_1, m m	S , mm	
1					9	882.6	11	11	4.2	17
2					15	1470.9	12	12.5	3.6	28
3	X12M	10	10	5	20	1961.3	12.5	13	3,1	38
4					25	2451.6	13	13.5	2.7	47
5					30	2941.9	14	14	2.2	59

After mechanical activation, a wear-resistant coating, titanium nitride, was applied to the samples. For the application of wear-resistant coatings, specialized Bulat-type plants were used, which are used in the laboratory of wear-resistant coatings of UlSTU. The mode of applying a wear-resistant coating by ion-plasma spraying included the following parameters: coating material - titanium nitride (TiN); coating thickness - 3 ... 4 µm; temperature - 480 °C.

As the parameter evaluating the increase in the resistance of the surface layer of the samples, we selected the parameter of the adhesive ability of the wear-resistant coating – the peeling coefficient Ko, a decrease in which indicates an increase in the adhesion strength of the coating with the tool base. To evaluate the adhesiveness parameter of a wear-resistant coating based on titanium nitride, it is proposed to use a device for testing preforms with a coating for peeling [9], which consists in fixing the minimum compression force of the springs at the moment of breaking the continuity of the protective coating (peeling).

In order to study the nature of the stress and strain state of the body during preliminary cold plastic deformation, a mathematical model of the process of cold plastic deformation (mechanical activation) using the LS-DYNA software package was developed, and an analysis of the adequacy of the obtained model is presented.

Draft processes were simulated using the LS-DYNA software environment, a multi-purpose program designed to analyze the nonlinear dynamic response of three-dimensional inelastic structures. It includes a fully automated process for solving contact problems, as well as many functions to verify the resulting solution that can successfully solve the most complex problems of impact, destruction and shaping.

The implementation of the modeling process consisted of 3 main stages: preprocessing; the solution of the problem; postprocessing processing.

When working with the LS-DYNA program, it was required to enter the values of stresses and strains in the form of true stresses and strains. At small strains, the values of the calculated and true parameters are almost identical. However, as the strains increase, these values diverge significantly. To obtain data on the plasticity of the material, the strain curve after uniaxial tension was used [5–7].

As a result of the simulation, a model of the sample sedimentation process was created with the overall dimensions corresponding to the samples precipitated during the full-scale experiment, physicomechanical characteristics, type and parameters of the material, type of contact, precipitation speed, striking motion maps and the time of completion of the precipitation process were determined and set.

The developed model of the precipitation process is presented in figure 2.

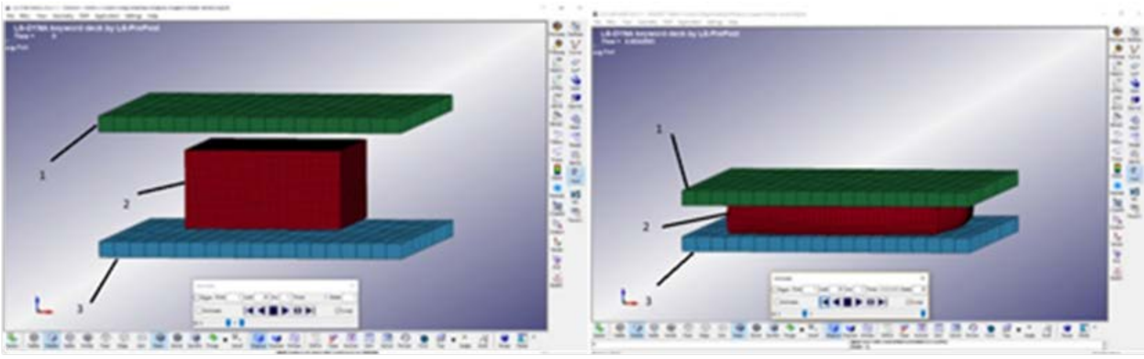


Figure 2. Model of the precipitation process performed in the LS-DYNA program: 1 – top striker; 2 – blank; 3 – lower striker.

As a parameter evaluating the adequacy of the physical model of precipitation with real results, we selected the dependence obtained by the results of modeling and a full-scale experiment, the precipitation effort on the degree of deformation. When processing the results of the experimental values and calculations in MS Excel , the dependencies were approximated, a graphical interpretation of which is shown in figure 3. In this case, the average statistical deviation of the results does not exceed 15%, which indicates the adequacy of the adopted model. Calculation errors can be reduced by increasing the elements involved in the calculation and, accordingly, the model calculation time. The resulting model, as can be seen from the graph (figure 3), quite correctly displays the results of a full-scale experiment (the discrepancy between the curves in the ΔF value does not exceed 5 ... 7 tc). An increase in ΔF for strains exceeding 40% occurs as a result of simplifications of the program calculation caused by the increased scale of the finite element mesh.

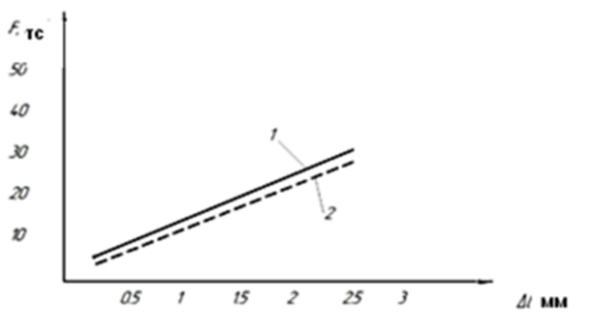
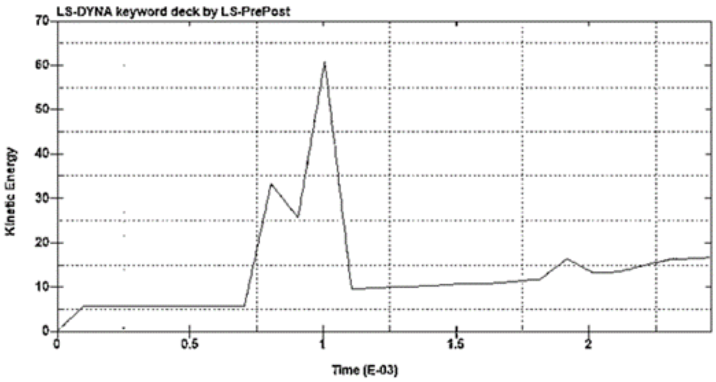


Figure 3. The graph of the dependence of effort on the degree of deformation F = f (Δl): 1– approximated curve obtained from the simulation results in LS-DYNA ; 2 – approximated curve obtained as a result of the experiment.

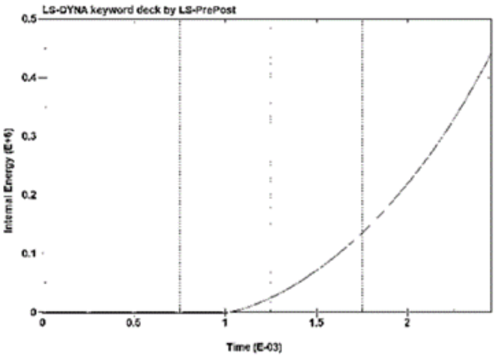
Analysis of the simulation allows us to conclude about the nature of loading during the upsetting process, as well as the distribution and magnitude of stresses. The maximum stresses arise at the boundaries of the deformable sample (angular stress concentrators), and with an increase in the loading speed and the upsetting force, the stress growth rate increases, which confirms the correctness of the developed physical model.

3. Conclusion

It is established that during the mechanical activation of the substrate, a change in energy is observed in the workpiece material. On rice nke 4 presents the results of a study of the kinetic and potential energy in the material samples during deformation in uniaxial compression scheme LS-program Dyna . A sharp jump in kinetic energy to the maximum value is characterized by the onset of a sharp metal flow. A further change is due to the gradual compaction of grains in the process of strain hardening. Over time, the metal flow decreases, so the change in the amplitude of the kinetic energy decreases.



(a)



(b)

Figure 4. Graphs of energy changes: a – kinetic energy of the workpiece in the process of deformation; b – potential energy of the workpiece.

Slowing the growth of potential energy is also due to the fact that in order to start the deformation, it is necessary to achieve stresses exceeding the yield strength of the metal. A further increase in energy is due to an increase in the dislocation density of the workpiece material and the force necessary for its deformation.

Analysis of the data obtained in the LS- Dyna program allows us to conclude about the nature of loading during the upsetting process, as well as about an increase in tensile stresses on the contact surface of the workpiece material (up to 1.6 · 103 MPa), which corresponds to the presented physical model, in which there is a decrease activation energy in the longitudinal direction of the crystal lattice (its tension). Maximum stresses arise at the boundaries of the deformable sample (angular stress concentrators), and with an increase in the loading speed and the upsetting force, the growth rate of tensile stresses on the contact surface increases, which confirms the correctness of the developed physical model.

The following stages of the study were completed: a methodology was developed for research and development of technology to increase the resistance of the surface layer; selection of materials and sizes of processed samples; The physical and computational models of the process of cold plastic deformation of specimens from tool heat-resistant steel X12M have been developed; The adequacy of this model and the possibility of using software environments to study the features and modes of cold plastic deformation are established. It is planned to continue research to increase the durability of the working parts of the stamping tool.

Acknowledgements
This work was supported by the Russian Fund for Basic Research – Grant No. 18-48-730-011.

References

[1] Khorshidi A, Vio-let J et al 2018 *Jornal Nature Catalysis* **1** 263–268
[2] Wang H et al 2016 *Science* **354** 1031–1036
[3] Agrawal P M, Rice B M et al 2002 *Surf. Sci.* **515** 21–35
[4] Browell R and Lin G 2000 *Ansys Solutions* vol 2 No 1
[5] Chernyavsky A O 2003 *Finite Element Method. Fundamentals of Practical Application* (Moscow: Mashinostroyeniye) p 24
[6] Kaplun A B et al 2003 *Ansys in the Hands of an Engineer: A Practical Guide* (Moscow: URSS Editorial) p 272
[7] Friedman Ya B 1974 *Mechanical Tests. Structural Strength. Part two* (Moscow: Mashinostroyeniye)
[8] Hwan A D et al 2012 Bulletin of the Voronezh State Technical University vol 8 No 5 131–134
[9] Ilyushkin M V et al 2003 Patent RU 37 221 U1 *Device for Testing the Coating for Peeling* 2003135362/20, 12/9/2003 Published: 04/10/2004 Bull. No. 10