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Calculation models for assessing the voltage-strain state of the state in the surface layer of parts during surface plastic deformation by rolling and smoothing

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Abstract
The paper substantiates the choice of a calculation model for assessing the voltage state during finishing-hardening processing, in particular, during shot-impact processing. Analytical dependences are given for calculating the components and voltage intensity in the surface layer of a semi-infinite body under the action of a distributed load on a spherical surface.

Keywords: Surface-plastic deformation, concentrated and distributed force, normal and tangential voltage, voltage intensity, contact area

Introduction

Most critical parts of machines and mechanisms (parts of working bodies) have high demands on the quality of the treated surfaces, determined by a set of geometric and physico-mechanical parameters: surface roughness, strength and hardness, residual voltage, dislocation density. The required quality of the surface layer of parts can be provided by finishing and hardening treatment, in particular, surface plastic deformation (PPD). This type of machining, being the simplest and most effective method of strain hardening, has now proven itself reliably and is therefore widely used in mechanical engineering.

The most simple to implement and effective in creating high quality surface layer of parts (favorable compressive residual voltage, low surface roughness, depth and degree of hardening (hardening)) are such methods of finishing and hardening processing as rolling and diamond smoothing. Despite the fact that when rolling around the ball in the contact zone, there is rolling with slipping, and when diamond smoothing - only sliding, there is a similarity between them regarding the nature of the deformation of the surface layer, the ratio of the acting forces and friction coefficients, as well as the regularity of the formation of the micro profile processed surface.

The high quality of the surface layer achieved by surface plastic deformation increases fatigue strength, contact endurance, wear resistance of parts and thereby increases the durability of machines and mechanisms.

Finishing and hardening of parts by rolling in and smoothing is characterized by the locality of plastic deformation of the surface layer. As a result of the force action of the deforming body, a deformation zone is created on the contact surface, the initial shape of which corresponds to the well, which determines a certain voltage-strain state along the thickness of the surface layer. Subsequently, as the rolling tool is smoothed in or smoothed with a deforming tool, the entire surface of the cylindrical part is covered by the deformation zone in the form of a continuous helical line due to the longitudinal feed, the degree of overlap of the current deformation zones depends on its value.

Owing to the locality of the process of interaction of bodies during the voltage-strain state of the surface layer of a part turns out to be inhomogeneous in thickness, there is a non-uniform elastic-plastic deformation with its characteristic features: the formation of compressive residual voltage, distortion of the crystal lattice and an increase in the density of dislocations, an increase in hardness.

The heterogeneity of the deformed state of the parts during surface hardening leads to heterogeneity of the voltage state along the depth of the surface layer. This model adequately describes the processes considered in the theory of friction and wear [1], when the model of

A single roughness is adopted in the form of a protrusion of a spherical or cylindrical shape.

To assess the voltage-strain state in the surface layer of parts during rolling in and smoothing, the following load models can be used [2], which differ in the type of load (concentrated or distributed force), the shape and law of load distribution at the boundary of a semi-infinite body:

1) A concentrated force P is applied at the boundary of a semi-infinite body.
2) A uniformly distributed load P is applied within the area of a circle at the boundary of a semi-infinite body.
3) The distributed load P_0 along the "hemisphere" (in proportion to the ordinates of the spherical surface) applied over the area of the circle at the boundary of the semi-infinite body (Fig 1).

The latest loading model most accurately reflects the mechanics of contact interaction when a ball is pressed into a semi-infinite body, because the result of this interaction is a plastically deformed zone in the form of a spherical surface. In the direction of penetration (along the z axis), the tangential voltage at the sites parallel to the coordinate planes are equal to zero ($\tau_{xy} = \tau_{zx} = \tau_{yz} = 0$). Consequently, normal voltage will be paramount.

The load distribution P over the area of a circle with radius a is represented by the ordinates h of the hemisphere built on this site:

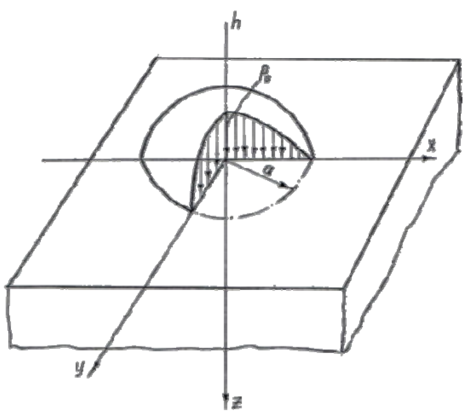

Fig 1: The design scheme for the voltage state created by the distributed load along the "hemisphere" at the boundary of a semi-infinite body

$$\frac{p}{p_0} = \frac{h}{a}, p = p_0 \cdot \frac{h}{a} = p_0 \sqrt{\frac{a^2 - (x^2 + y^2)}{a^2}} = p_0 \sqrt{1 - \frac{x^2 + y^2}{a^2}},$$

Where p_0 – is the pressure in the center of the circular platform F; p –ressure corresponding to the ordinate of the h hemisphere.

The largest load P will be:

$$P = \int_F p dF = \frac{p_0}{a} \int_F h dF,$$

Where $\int_F h dF = \frac{2}{3} \pi \cdot a^3$ - volume bounded by a hemisphere radius. Hence,

$$p_0 = \frac{3}{2} \cdot \frac{P}{\pi \cdot a^2} \quad (1)$$

Thus, when the load is distributed over the "hemisphere", the highest pressure is 1.5 times its average value. The voltage components under a load distributed over a circular contact are determined by the dependencies:

$$\sigma_Z = -p_0 \frac{1}{1 + \left(\frac{z}{a}\right)^2};$$

$$\sigma_Y = \sigma_X = -p_0[(1+\mu) - \frac{1}{2} \cdot \frac{1}{1 + \left(\frac{z}{a}\right)^2} - (1+\mu) \cdot \frac{z}{a} \cdot arctg \frac{a}{z}] \quad (2)$$

Where z – is the distance to some considered point of the surface layer; μ – poison's ratio.

Due to the axial symmetry of the voltage state in the case of a circular contact area, we have $\sigma_x = \sigma_y$. Normal voltage σ_x and σ_y, in contrast to σ_z, depend on the elastic properties of the material (Poisson's ratio). If in formulas (2) we take z = 0, then

$$\sigma_Z = -p_0; \sigma_X = -p_0 \frac{1 + 2\mu}{2} = \sigma_Y \quad (3)$$

As $\sigma_Z = \sigma_1; \sigma_X = \sigma_Y = \sigma_2 = \sigma_3$ and $\sigma_i = |\sigma_1 - \sigma_2|$, then the voltage intensity is

$$\sigma_i = p_0[\frac{3}{2 \cdot (1 + \left(\frac{z}{a}\right)^2)} - (1+\mu) \cdot (1 - \frac{z}{a} \cdot arctg \frac{a}{z})] \quad (4)$$

This calculation model of loading is applicable for the analytical description of contact interaction during shot-impact processing of machine parts [3] for the purpose of strain hardening. The voltage intensity σ_i calculated by formula (4) allows us to further determine the level of specific stored energy U_s [4, 5], which is an energy criterion for the quality of the surface layer of parts after final machining and is responsible for the residual voltage state. The assessment of the stored strain energy in the surface layer of parts after machining is based on several reasonable approaches that take into account the basics of the theory of dislocations, the thermodynamics of irreversible processes, and the energy analysis of the material deformation diagram.

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