DETERMINATION OF DEFORMATION AND MACHINING ALLOWANCE OF PRECISION PARTS HARDENED BY LASER METHOD

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Abstract

In laser diffusion metallization, precision parts of machines and equipment are heated to a temperature of 1100-1250 °C. Deformation of parts occurs at this temperature. Another reason for the deformation of parts when increasing the strength of the surface with laser technology can be the normalization of the internal stresses of the parts. Deformation of products under conditions of exposure to high temperatures can also arise from its own weight, which is not possible during diffusion processes in densely packed powder environment, but is possible with other saturation methods (gas, vapor vacuum, liquid). The characteristic of the variation of the value of the deformation depending on the thickness of the diffusion zone. The value of the deformation changes with the change of Poisson's ratio. The article is devoted to the determination of the change value of bending during nanodiffusion metallization.

Keywords: stresses, crystallograph, machining, deformation, metallization, laser, nanodiffusion.

I. Introduction

Literature analysis shows that increasing the surface hardness of precision parts by laser has not been fully investigated. When increasing the surface strength of precision parts with a laser, temperature deformations (bending) inevitably occur [1 - 4].

The main reason for deformation is the change of thermal regimes in surface strengthening during nanodiffusion metallization of parts. The higher the cooling rate and the heating temperature, the higher the resulting thermal stresses and their induced deformation [5 - 8]. Therefore, the deformation is inevitable and irreversible, but the change of the geometrical parameters of the deformation can be affected by the heating temperature and the cooling mode [9 - 14].

Another reason for the deformation of parts when increasing the strength of the surface with laser technology can be the normalization of the internal stresses of the parts. Thus, according to Yu.M. Lakhtin [15], compressive stresses in the surface layer after nitriding are 600...800 MPa, and tensile stresses in the depeer layers - in the transition zone - are 200...300 MPa.

Ya.E. Geguzin shows two main reasons for the occurrence of these stresses [16]. The first of them is that there is a crystallographic mismatch of existing phases at the "layer-core" boundary, which is characterized by the value of the dimensionless ratio $\Delta a/\bar{\alpha}$, where Δa is the difference in the parameters of the contact phases; $\bar{\alpha} = \frac{a_1 + a_2}{2}$ is the arithmetic mean of the phases. Crystallographic mismatch causes tangential stresses that can reach a maximum value at the plane of the interfacial boundary.

$$\sigma_\tau^{\Delta a} \approx G\frac{\Delta a}{\bar{\alpha}} \quad (1)$$

where G - is the displacement modulus. $\Delta a/\bar{\alpha} = 5{\cdot}10^{-2}$, $G = 5{\cdot}10^6$ N/sm², $\sigma_\tau^{\Delta a} = 2{,}5\text{-}10^5$ N/sm² [16].

Full normalization of internal stresses does not occur. The size of the residual elastic stresses should not exceed Payerls limit $\sigma p = (10^{-4}..\ 10^{-5})$ G, that is, the value at which dislocations will shift relative to each other – $\sigma \le \sigma_P$. Due to these stresses, the growth of the bending increases with the increase in the thickness of the diffusion layer.

"The second type of stress in the "layer-core" system occurs when the precessed workpiece, which has different coefficients of linear expansion of the layer and the core, cools. The value of these stress is as follows [16].

$$\sigma_\tau^{\Delta T} = G\Delta a T \quad (2)$$

where $G = 5{\cdot}10^6$ N/sm²; $\Delta a = 10^{-5}$ °C⁻¹; $\Delta T = 10^{3}$°C; $\sigma_\tau^{\Delta T} = 10^4$ N/sm².

Deformation of products under conditions of exposure to high temperatures can also arise from its own weight, which is not possible during diffusion processes in densely packed powder environment, but is possible with other saturation methods (gas, vapor vacuum, liquid).

The purpose of the work is to investigate the main cause and theoretical determination of the deformation caused by the technological process of laser surface hardening. In addition, it is necessary to study the influence of the deformation parameters on the geometrical parameters of precision parts.

II. Research Methodology

It is almost impossible to avoid bending of the part during surface hardening with laser technology. Therefore, in order to meet the technical requirements for hardening the surface of precision parts of machines and devices with laser, it eliminates bending by increasing the thickness of the layer and by machining. In this regard, research on the possibility of increasing the surface strength of such high-precision parts with laser technology is required. Let's explain this with Fig. 1.

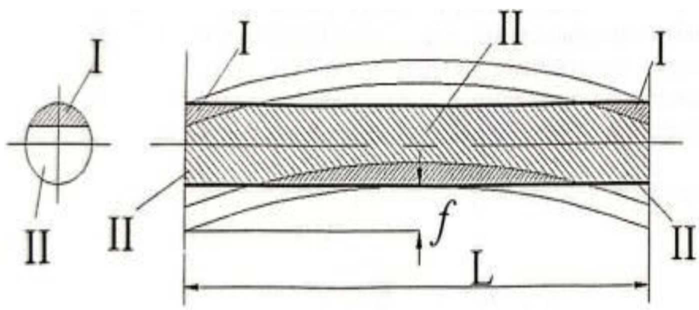

Figure 1: *Machining scheme of the bending of the precision part by laser surface-hardened*

It can be seen from Fig. 1, that it is possible to eliminate the bending (f) by machining. During machining, the thickness of the layer appears in II. A limit layer is a must to ensure surface hardening after processing. This is shown in Fig. 2.

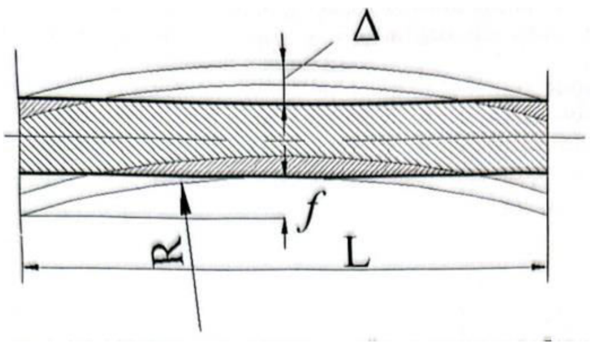

Figure 2: *Determining the limit value of bending*

From Fig. 2, it can be seen that the maximum value of the diffusion layer is greater than the geometrical dimensions of the bending, which allows to meet the mechanical demand implemented on precision details by machining. Thus, the condition that the deformation of parts in the diffusion zone does not occur can be written:

$$\Delta > f \tag{3}$$

where, Δ - is the thickness of the diffusion layer.

It is known from the theory of elasticity that the bending value of the precision part in the elastic deformation zone [17]:

$$f = \frac{q * L^4}{48\, E\, I_x} \tag{4}$$

where,

q – the stress in the part causing the bending moment, MPa;

L – part's lentgh, mm;

E – modulus of elasticity of the material, MPa;

Ix – moment of inertia of the cross section, mm^3.

As a result of laser surface hardening, the plasticity of the part increases. At this time, a sharp decrease in the modulus of elasticity (for example, 42.5% for iron at 1000°C) occurs, which leads to the normalization of the internal stresses present in the workpiece [6]. Eq. 2 would be valid within the limits of Hooke's law. It follows that in the presence of a deformation moment, the bending moment is directly proportional to the value of the stresses, to the fourth degree to the length of the section, and inversely proportional to the modulus of elasticity and the moment of inertia of the curve.

The value of the deformation of the precision part can be expressed by the thickness of the diffusion layer and the stresses present there [4]:

$$f \approx \frac{L^2}{8R} = \frac{3 * d_n * L^2 * (1-\mu) * \Delta * \delta_c}{4(d_n + \Delta)^3} \tag{5}$$

where,

R - is the radius of curvature of the bend;

d_n - diameter of the precision part, mm;

μ - Poisson's ratio;

δ_c - the value of the relative change in the dimensions of the precision part along the line of action of the stress,

$$\delta_c \approx \frac{2\Delta}{d_n} 100\% \tag{6}$$

From this dependence, it follows that the value of bending is directly proportional to the square of the length of the precision part. Due to the increase in the thickness of the diffusion layer, while compensating the bending during the machining of the precision part, it allows the surface layer to remain at a thickness that ensures the wear resistance of the part.

The characteristic of the variation of the value of the deformation depending on the thickness of the diffusion zone is shown in Fig. 3. The curves were constructed according to the Eq. 5, assuming d_n = 9 mm, L = 51 mm, geometric dimensions of the plunger of the fuel device: μ_1 = 0.5, μ_2 = 0.2. By changing the value of Δ, the graph of f = F(Δ) is constructed. It follows from Eq. 5 that the value of the deformation changes with the change of Poisson's ratio. It can be seen from the figure that as the thickness of the diffusion layer increases and the coefficient (μ) decreases, the deformation increases.

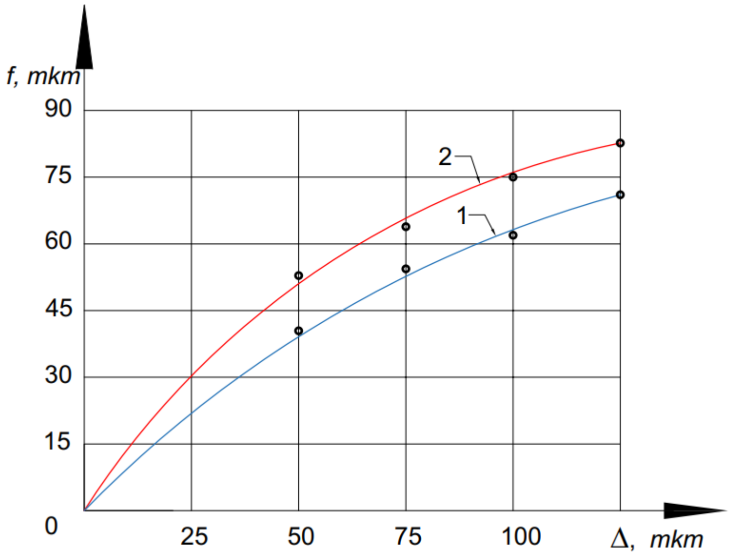

Figure 3: *Dependence of the value of bending (f) on the thickness of the diffusion zone (1-μ=0.5; 2- μ=0.2)*

III. Discussion of the results obtained

In laser surface hardening, the nanodiffusion layer is evenly distributed on the surface of precision parts. In laser surface hardening, the change of the geometric shape of the layer in the precision part after the technological process depends on the quality of the previously processed parts, metallization modes, etc. it depends. This will affect the allowance of the nanodiffusion layer removed during machining.

The calculation of the minimum required diffusion layer for machining of precision parts was developed based on the analytical calculation method proposed by Professor B. P. Kovan [18].

When processing internal and external surfaces, the minimum allowance for barel and shaft type parts according to V.M. Kovan's formula is calculated by the following formula [18].

$$2z_{min} = 2\left[\left(R_{z_{i-1}} + T_{i-1}\right) + \sqrt{p_{i-1}^2 - \varepsilon_i^2}\right] \tag{7}$$

where,

$R_{z_{i-1}}$ - the height of the disparity achieved after the previous operation;

T_{i-1} - the depth of the defective surface layer after the previous operation;

p_{i-1} - spatial deviation of the processed surface relative to the main surfaces of the workpieces obtained in the previous operation;

ε_i - installation error in the placement of precision parts when performing the operation.

In the finishing operation, the displacement of the axis of the precision parts relative to the outer surface is not corrected, i.e. p_{i-1}= 0. The installation error is zero, because the tool used in finishing and precision parts act as a base for each other during processing, i.e. $\varepsilon_i = 0$.

When processing a nanodiffusion layer in laser surface hardening, there is no defective surface layer, because the properties of the layer in depth are practically the same and do not change during the machining $T_{i-1} = 0$.

The main indicator of quality in the technological process of finishing is the roughness of the surface. It is clear from the Eq. 7 that the minimum allowance for the delivery of the diffusion layer is: $z_{min} = R_{z_{i-1}}$.

Eq. 7 does not take into account the effect of the initial geometrical failure on the allowance.

Geometrical failure (deformation, ovality, conicity, barreling, etc.) obtained after the laser surface hardening process are 5...6 times greater than the value of form deviations allowed from previous operations [8]. This determines the allowance during the finishing operation. The deformation after the laser technological process is 6 μm on average [19].

Therefore, the Eq. 7 for calculating the allowance in the finishing operation is expressed by the following formula:

$$Z_{min} = \kappa_i + \sum_{i=1}^{n} R_{z_i} \tag{8}$$

where,

κ_i – the largest failure of the part after laser surface hardening;

n – number of finishing operation.

After the laser surface hardening process, the main variable of precision parts is deformation, which includes other failurer.

From here:

$$\kappa_i = f_{\kappa p} \tag{9}$$

where, $f_{\kappa p}$ – deformation of precision parts.

$f_{\kappa p}$ - quantity can be found using the equation proposed in Eq. 5 [20].

$$f_{\kappa p} \approx \frac{L^2}{8R} = \frac{3 * d_n * L^2 * (1-\mu) * \Delta * \delta_e}{4(d_n + \Delta)^3} \tag{10}$$

where,

R - is the radius of curvature of the deformation, mm;

L - the length of the precision section, mm;

d_n- diameter of the precision part, мм;

μ - Poisson's ratio;

δe - the value of the relative change in the dimensions of the precision part along the line of action of the stress;

Δ - thickness of the nanodiffusion layer.

$$\delta_e \approx \frac{2\Delta}{d_n} \tag{11}$$

The final formula for the machining allowance (z_{min}) during machining of precision parts with laser surface hardening is as follows.

$$z_{min} = \frac{3}{4} \frac{d_n * L^2 * (1-\mu) * \Delta * \delta_e}{(d_n + \Delta)^3} + \sum_{i=1}^{n} R_{z_i} \tag{12}$$

During the machining of precision parts with a surface hardened by laser, a relationship was established along the processing allowance, the deformation in the parts, and the total height of the micro-roughness in the previous operation.

By knowing the thickness of the layer in laser surface hardening, we can determine the minimum required allowance for processing.

Determination of the minimum allowance after the laser surface hardening of the plunger of the fuel device in the YaMZ engine: the diameter of the plunger - 9 mm; plunger length - 51 mm; according to the experiment, the total height of the microroughness is 0.0016 mm; the value of δ_e is equal to 0.008 for the thickness of the diffusion layer - 0.125 mm; Poisson's ratio - 0.5 [21];

$$z_{min} = \frac{3 \bullet 9 \bullet 51^2 \bullet (1-0,5) \bullet 0,125 \bullet 0,008}{4 \bullet (9+0,125)^2} + 0,0016 = 0,107$$

According to the experimental data, the thickness of the layer for machining is in the range of 0.1-0.110 mm, which is in good match with the theoretical data determined by the Eq. 12.

IV. Conclusion

Thus, it follows from the above that in increasing the surface strength of precision parts with a laser, the deformation of the parts, as well as the allowance of machining, should be taken into account.

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