Application of Non-Destructive Testing Methods for Analysis of Parameters of the Surface Layer State after Mechanical Processing

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Abstract. The paper presents a study aimed at describing the effect of machining parameters on the structural state of the surface layer on the basis of the mechanics of technological inheritance. The samples were controlled by the methods of nondestructive testing and the study of the values of microhardness. Dependencies between the results of the control and the method and treatment regimes are given.

Introduction

At present, there are many approaches to ensuring the ex-operational properties of machine parts. A number of studies have been carried out to determine the influence of the parameters of machining on the quality of the surface layer, as well as the quality of the surface layer on the operational properties [1, 2]. A more integrated approach to the development of technological processes, it is possible to develop on the basis of the apparatus of the mechanics of technological inheritance [3, 4]. By now in most works the description of technological inheritance boils down to difficultly applicable mathematical formulas that do not allow one to unequivocally determine the effect of inheritance on the parameters of the surface layer.

The goal is to develop the mechanics of technological inheritance in the direction of describing the parameters of the mechanical state in terms of the parameters of the structural-phase state of the material. To achieve this goal, a number of tasks are formulated:

1. To develop a structural-analytical model of the hereditary formation and transformation of the structural-phase state of the metal of the surface layer at the stages of machining.

2. To develop a methodology for experimental studies of the hereditary formation and transformation of the structural-phase state of the metal of the surface layer at the stages of mechanical processing.

3. To develop a complex of mathematical models characterizing the hereditary influence of the regularities of plastic flow on the formation of the structural-phase state of the metal of the surface layer, as well as the dependence of the parameters of the structural-phase state on the accumulated deformation of shear and the depletion of the plasticity reserve.

4. Develop a functional model for the design of technological processes that provide specified parameters of the structure and, as a consequence, certain operational properties.

In this paper, we present a structural-analytical model, the results of using non-destructive testing methods, as well as the results of measuring microhardness.

In the course of solving the set tasks, a structural-analytical model was developed reflecting the concepts of "Formation and transformation of the structural state" (Fig. 1) [5].
In accordance with the developed model, at the stages of the life cycle, the structural state of the surface layer of the article is formed and transformed from the initial state to the final one. These processes occur due to the impacts of both technological and operational, the regularities are determined by the properties of the material.

The most interesting for us is "the formation of a structural state at the stage of machining" (Fig. 2), the block A1.1 at the output forms the parameters of the deformation focus (geometry, qualitative and quantitative picture of the distribution of the parameters of the stress-strain state) in accordance with regimes processing, the parameters of the deformation focus are, in turn, the mechanism for forming the loading program A1.2. Block A1.3 gives the output indicators of the structural state formed depending on the properties of the material and the mechanism of a certain loading program. Exhaustion of the stock of plasticity A1.4 is determined by the properties of the material, the process mechanism is the indicators of the structural state, the output is a structural state at the stages of processing and loading history.

The type of loading program can be considered the determining factor for the formation of a structural state.
Fig. 2. Decomposition A1 "Formation of a structural state during machining": SSis – the initial structural state of the material, MP is the material properties, SSpm - structural state of the metal after machining

**Material and methods of investigation**

To use this model, it is necessary to describe the connections between its elements from the mathematical point of view. Development of mathematical models requires a number of experimental studies, including:

1. Mechanical processing of certain modes, which will allow establishing relationships between the parameters of the stress-strain state of the surface layer after machining and the parameters of the structural-phase state.

2. Study of the parameters of the mechanical and structural-phase state of the processed samples by methods of nondestructive and destructive testing.

Fig. 3. Appearance of the sample

In Fig. 3 shows the appearance of the sample, the designations M1, M2 and M3 correspond to modes 1, 2 and 3 (Table 1), the processing will be performed both operationally (ie, in certain sections of the sample the cutting will be performed according to the corresponding regime) and sequentially this is successively cut by the modes M1 and M2, M1 and M2 and M3).

The sample material is 40X steel. Before machining by cutting, the workpiece was subjected to heat treatment: recrystallization annealing $T = 600^\circ C$, time 60 min.
After the mechanical processing, studies of samples with spectral-acoustic control and magnetic-noise control are planned, these monitoring methods were adopted as well-proven in the diagnosis of accumulated damage to FEC equipment [6, 8] and evaluation of the state of the metal in simple deformation [9]. From destructive testing methods, measurements of the microhardness values [10] of the surface layer have been performed, and optical and transmission electron microscopy is planned.

The control of samples by the spectral-acoustic method was carried out by the automated acoustic system ASTRON. The control of samples by the method of magneto-noise control was carried out by the stress analyzer and the “Introscan” structure. Measurement of the microhardness values of the surface layer was performed using a Durascan 20 microhardnesser [7, 10].

Results and its discussion

The control zones of non-destructive testing methods are shown in Fig. 4, and the results of the control are presented in Table 2 and Table 3, as well as in Fig. 5-7.

![Fig. 4. Zones of research by non-destructive methods of control](image-url)

As studies have shown by the method of spectral-acoustic control, processing from the initial state according to the regime of "rough" cutting causes the delay time and the average amplitude of the signal to increase, which indicates changes occurring in the surface layer under the action of cutting forces.

In sequential processing by modes corresponding to the "rough – semi-pure" processing, the value of the signal delay time is higher than in the "semi-pure – finished" mode for operational processing. With "finished" processing, the delay time of the signal decreases, both in the case of sequential and operational processing. The values of the average amplitude of the signal for sequential processing are somewhat lower than in the operating room, which may be due to the introduction of high voltages into the surface layer of the metal.
The results of sample control by the spectral-acoustic method

| №  | Processing mode | The delay time of the signal R, ns | The attenuation coefficient K | The average amplitude of signal A |
|----|-----------------|-----------------------------------|------------------------------|---------------------------------|
| 1  | The initial state | 4622                             | 0.42                         | 46                              |
| 2  | M1              | 4655                             | 0.13                         | 181                             |
| 3  | M2              | 4651                             | 0.08                         | 232                             |
| 4  | M3              | 4651                             | 0.08                         | 187                             |
| 5  | M1+M2           | 4652                             | 0.13                         | 176                             |
| 6  | M1+M2+M3        | 4647                             | 0.15                         | 145                             |

Fig. 5. Dependence of the signal delay time on the mode and the processing sequence

Fig. 6. Dependence of the average signal amplitude on the mode and sequence of processing
The results of the control of samples by the method of magneto-noise control.

| №  | Processing mode | The average value of the intensity of magnetic noise |
|----|-----------------|--------------------------------------------------|
| 1  | The initial state | 109.5                                            |
| 2  | M1              | 201.7                                            |
| 3  | M2              | 198.2                                            |
| 4  | M3              | 197.0                                            |
| 5  | M1+M2           | 218.3                                            |
| 6  | M1+M2+ M3       | 202.2                                            |

Fig. 7. Dependence of the intensity of magnetic noise on the mode and sequence of processing.

For all processing methods, the magnetic noise increases from the initial state to the "rough" mode. In sequential processing by modes corresponding to the "rough – semi-pure" processing, the intensity of magnetic noise is higher than in the "semi-pure – finished" mode for operational processing. With "finished " processing, the intensity of magnetic noise decreases, both in the case of sequential and in operating processing.

The microhardness measurement scheme is shown in Fig. 8 [7], and the results of the control in Fig. 9.
According to the results of the study, it is seen that when processing by "cutting" modes, a decrease in the value of microhardness is observed, which indicates a slight softening of the surface layer. With further sequential processing by the appropriate "rough – semi-pure " processing, an increase in microhardness is observed compared to processing in " semi-pure -finished" mode for operating processing, however, when machining in " finished " mode for all processing methods, the microhardness value is equalized.

Fig. 9. The dependence of the average microhardness of the surface on the regime and the processing sequence
Conclusion
1. A structural-analytical model has been developed that reflects the concept of "Formation and transformation of the structural state" in accordance with which the main factor determining the parameters of the structural-phase state after machining is the loading program.
2. Studies were carried out using spectral-acoustic and magnetic-noise control. It is established that, depending on the method and treatment regime, similar dependencies are observed.
3. Investigations of the distribution of the values of microhardness are performed. It was found that the dependence of microhardness on the cutting regimes and processing method correlates with the results of non-destructive testing.
4. At present, investigations are being carried out using the methods of optical and transmission electron microscopy to establish the dependencies between the modes and processing methods and the parameters of the structural-phase state.

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