APPLICATION OF THE CRITERION OF TECHNOLOGICAL DAMAGEABILITY IN MECHANICAL ENGINEERING

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ABSTRACT

Development and implementation in mechanical engineering practice of integrated information systems for control of technological processes of manufacturing products is the main driver of economic growth of developed countries. The priority of modern engineering technology is to provide the specified operational characteristics of products in accordance with the accuracy parameters, set by designer and quality of surface layers in contrast to achieving the minimum technological cost with maximum performance for traditional approaches. Technological providing of the main operational characteristics of the product (bearing strength, wear resistance, fatigue strength, joint strength etc.) require a systematic approach, which consists in the investigation of real physical processes at submicroscopic, microscopic and macroscopic levels of research, and step-by-step tracking required parameters at all stages of the Product Life Cycle from the position of technological inheritability. It is proposed to use the method of LM-hardness to control the quality of the structure of the material from castings in the design of functionally-oriented processes. The magnitude of the technological damage of the product material serves as a criterion for optimization when choosing a variant of surface treatment of the casting. A method for providing experimental studies of castings of aluminium alloys has been developed. On the basis of the carried-out experimental researches the rational route of processing of surfaces of casting is chosen.

Keywords: surface engineering, technological inheritability, functionally-oriented process.

INTRODUCTION

Technological providing operational characteristics of products when designing the functionally-oriented technologies is a priority task of modern mechanical engineering production (Kusyi & Kuk, 2020; Stupnytskyy & Hrytsay, 2020).

Functionally-oriented technological process (FOTP) is a technological process that aims to provide the most efficient operational characteristics of the product in compliance with the parameters of accuracy and quality of the product surface layer assigned by the designer. Solution of this problem is possible due to automated control of the process and careful analysis of the entire technological chain of manufacturing parts from the position of technological inheritability, by the system-integrated CAD/SAE/CAPP/CAM software products. During the implementation of FOTP, the design and technological preparation of production is intensified to provide the maximum positive result in the customer-manufacturer chain (Stupnytskyy & Hrytsay, 2020).

However, the lack of effective criteria for assessing quality parameters, operational characteristics and reliability indicators of products, taking into account the technological inheritability of properties when designing FOTP retards the introduction of rational technologies in engineering practice.

The technological process has a direct and decisive influence on the quality parameters of products starting from the blank production to the final product. However, the process of formation of the operational characteristics and reliability indicators of the product at the stage of its creation can lead under adverse conditions to the product fracture at the stage of its operation (Kusyi & Kuk, 2020; Kusyi, Kuzin, & Kuzin, 2017). This is due to the complexity and ambiguity of the relationships between the quality parameters of the product, its operational characteristics and reliability indicators (Figure 1).

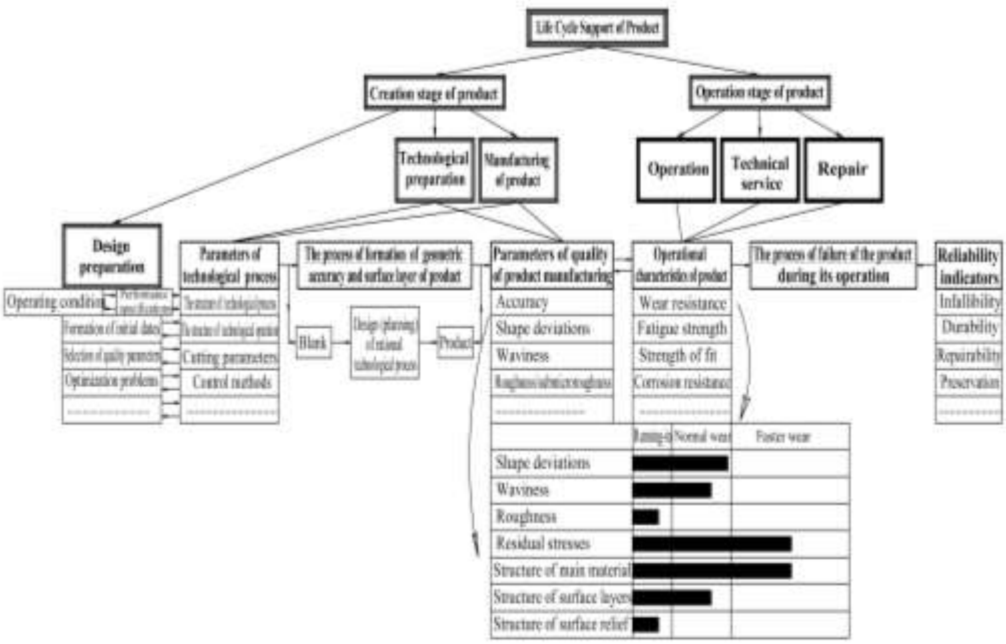

Figure 1. Relationships between parameters of technological process, surface quality parameters, operational characteristics and reliability indicators

The imperfect technological process causes inadmissible failures of the product, which are classified into three groups (Figure 2) (Pronikov, 1978; Kusyi, 2019).

The first group of causes is connected first of all with shortcomings of the designer's work at a stage of production preparation. Such failures are embedded in the products at the stage of technological preparation of production and are implemented during their manufacturing (Figure 2) (Pronikov, 1978; Kusyi, 2019).

The second group of causes that lead to unacceptable failures due to technology is related to the insufficient reliability of the technological environment. The technological environment is a set of technological objects that interact with the studied technological object at a certain stage of manufacturing parts and / or assembly of the machine (Figure 2) (Pronikov, 1978; Kusyi, 2019).

At this stage of mechanical engineering development, the third group of causes of unacceptable failures is the least studied. The third group is related to residual and side effects that are formed during the process (Figure 2) (Pronikov, 1978; Kusyi, 2019). It is worth noting that all subgroups of group III are interconnected. The processes of occurrence and formation of defects at the stage of product creation due to the phenomenon of technological inheritance of properties can have two development options. According to the first option, the processes of occurrence and formation of defects can progress and develop into damage during operation. According to the second option, their impact can be minimized or even completely eliminated due to the rational structure of the technological process.

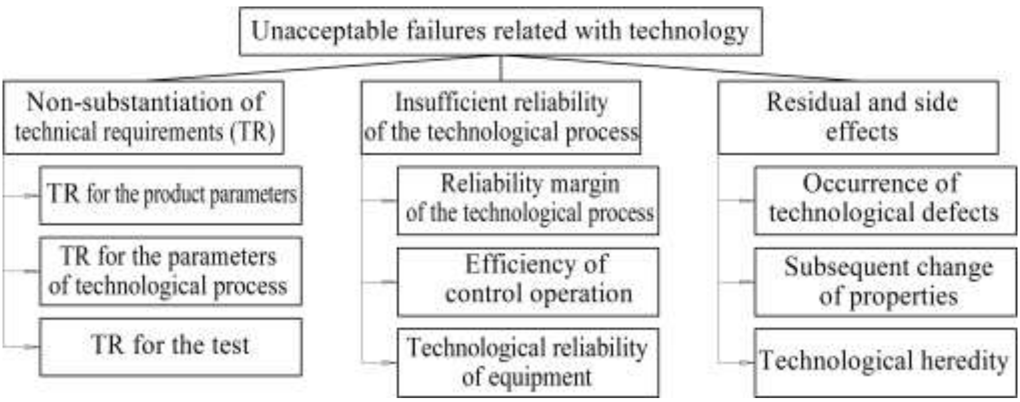

Figure 2. Classification of unacceptable failures associated with technological processes imperfections

Technological providing of the main operational characteristics of modern products requires a systematic approach, which consists not only in the study of real physical processes at all levels: submicroscopic, microscopic and macroscopic, but also in their step-by-step tracking at all stages and stages of the Life Cycle of a Product (Denkena et al., 2014). Technological inheritability is the process of transferring the object properties from previous technological operations to subsequent ones. Preservation of these properties for the object is called technological heredity. According to this approach the system principle of realization of the Life Cycle of a mechanical engineering product from the position of technological inheritability requires a direct connection of technological preparation of production with the stage of operation with not step-by-step, but parallel, coordinated work of designer and technologist. Therefore, both technological transitions of separate operations and operations of technological processes of machine details manufacturing need to be considered in interrelations, analyzing all technological chain from the blank production to finished products, when forming their final parameters.

MATERIAL AND METHODS OF WORK

Inheritability of product properties during their manufacture and assembly is most often described using graph theory.

The quality parameter on the p-th technological operation is changed by introducing the coefficients of technological inheritability (Jashcheritcyn, Ryzhov, & Averchenko, 1977):

$$
\begin{aligned}
&R_1 = a_1 \cdot R_0^{b_1};\\
&R_2 = a_2 \cdot R_1^{b_2};\\
&\dots\dots\dots\dots\dots\dots \qquad (1)\\
&R_{p-1} = a_{p-1} \cdot R_{p-2}^{b_{p-1}};\\
&R_p = a_p \cdot R_{p-1}^{b_p}.
\end{aligned}
$$

where $R_0 \ldots R_p$ – set of quality parameters; a_1, b_1, .. a_{p-1}, b_{p-1}, a_p, b_p – coefficients of technological inheritability according to the sequence of operations of the technological process.

According to (1), the technological chain is described by the coefficients of technological inheritability, which connect the main functional relationships between technological modes and product quality parameters. These coefficients are obtained by transforming the regression dependences found by the methods of planning extreme experiments (Jashcheritcyn et al., 1977):

$$R_p = a_p \cdot a_{p-1}^{b_p} \cdot a_{p-2}^{(b_p \cdot b_{p-1})} \cdot \ldots\ldots\ldots a_1^{(b_p \cdot b_{p-1} \cdot \ldots \cdot b_2)} \cdot R_0^{(b_p \cdot b_{p-1} \cdot \ldots \cdot b_1)} \quad (2)$$

From formula (2) it follows that the final parameter of product quality is related with the initial parameter of blank quality through a set of coefficients of technological inheritability.

Determining all the coefficients of technological inheritability significantly complicates the work at the stage of technological preparation of production.

Consider in detail the relationship between the parameters of the technological process, the parameters of processing quality, operational characteristics and reliability indicators from the position of technological inheritability of properties (Figure 3). The Life Cycle of a Product includes the development and production stage and the stage of product exploitation. The development and production stage contains the substages of design preparation, technological preparation of production and the stage of product manufacture. The stage of exploitation includes the use, technical service and repair of the product (Figure 3).

In our opinion, the technological inheritability of the properties of products at the substages and stages of their Life Cycle should be analyzed using their technological damageability.

In the general case damage is a process of bright and uneven change of a geometrical condition of friction surfaces, structure and properties of the surface layers. Damage is the result of damageability, which is manifested in changes in macro-geometric characteristics, structure, properties and stress state of the product surface layers. On the other hand, the analysis of the Life Cycle of a Product shows that the damage is the result of its operation due to the «rebirth» of the defects formed at the development and production stage. The properties of the product (machine) are determined by the properties of the blanks and the forming technological environment, which is the carrier of the mechanism of inheritance and transformation of the properties of products in the process of their manufacture (Suslov & Dalskyj, 2002), which is shown in Figure 3.

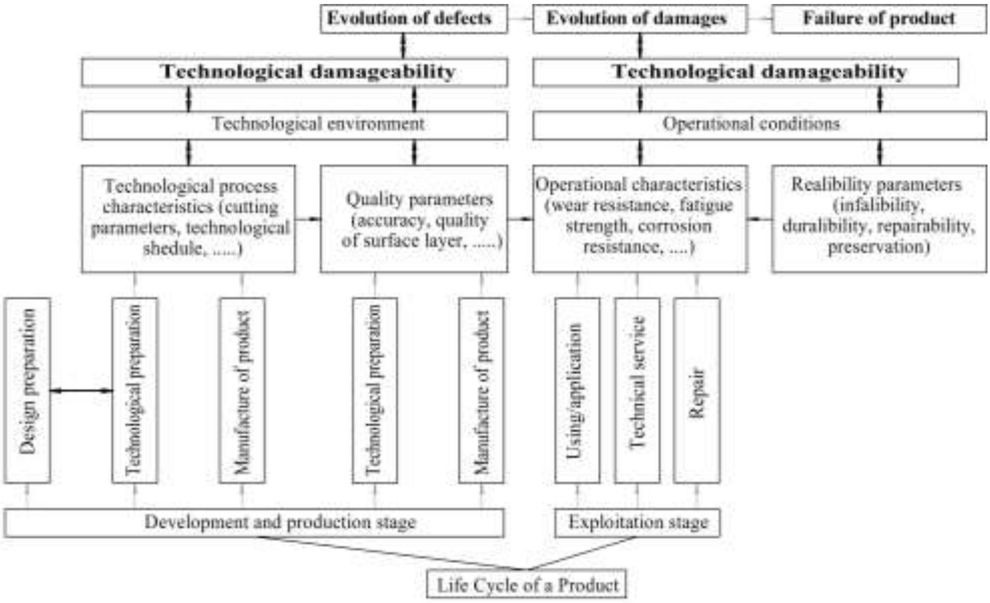

Figure 3. Analise of Life Cycle of a Product by means of its technological damageability

In the product manufacture process, defects occur depending on the processing modes, control methods, the degree of automation etc. For each technological process, as a rule, there are typical types of defects associated with a violation of the technological process or an unfavorable combination of factors (Pronikov, 1978). The origin, occurrence and development of defects are the result of the technological process of product manufacture, and a damage is a consequence of its operation (Pronikov, 1978) (Figure 3).

According to the classical postulate of mechanical engineering technology, machining has a significant impact on the workability of products.

However, currently, operating conditions are a priority for the development of product damage in their Life Cycle.

Analyzing the technological damageability of the product during its Life Cycle, you can predict the probability of its failure for specific operating conditions.

The processes of damage evolution from the development and production stage to the exploitation stage of Life Cycle of a Product are multi-scale and multi-stage. They develop simultaneously at the submicroscopic, microscopic and macroscopic levels thus meaning the combination of different types of models. Multi-stage processes require new approaches and techniques to solve technological problems depending on the operating conditions of the product.

Therefore, to identify the cause of the product failure due to its damage, the entire technological chain from the blank to the final product for its executive surfaces, taking into account the technological inheritability of the properties, must be analyzed.

According to the provisions of the Continuum Damage Mechanics (Murakami, 2012):

$$\widetilde{M} = \frac{M}{1 - D_M}, \tag{3}$$

where M, $\widetilde{M}$ – the value of the true and effective properties of the material , respectively; D_M – kinetics of damage accumulation (damageability) for a given property of the material.

It is established that the main dominant parameters of material depletion are the processes of damage accumulation associated with loosening of the material, which leads to degradation of its modulus of elasticity and other physical and mechanical properties for two types of fracture: tear – E and shear – G. Material damage under axial load – D_σ and under shear – D_τ are the parameters of material degradation assessment for different operating conditions (Murakami, 2012):

$$D_\sigma = 1 - \sqrt{\frac{\overline{E}_i}{E_0}}. \tag{4}$$

$$D_\tau = 1 - \sqrt{\frac{\widetilde{G}_i}{G_0}}. \tag{5}$$

Application of dependences (4), (5) in engineering practice requires special equipment and qualified personnel to conduct experimental research, so it is difficult to implement them at the mechanical engineering plant.

The calculation of technological damageability depends on the blank type for a given product. In this paper we will consider the method of calculating the technological damageability for a casting block.

In the last decade, in solving applied problems, the method of LM-hardness, developed under the guidance of Academician A.O. Lebedev, was used. The damage parameter for the LM-hardness method is not the absolute value, but the degree of scattering of the characteristics of the material mechanical properties on the destroyed samples after operation at different stress levels. This method is easiest to implement, using hardness as a mechanical characteristic, the value of which is used to indirectly assess the properties of materials (Lebedev, 2003; Lebedev et al., 2012).

Homogeneity is the parameter that integrally characterizes the state of the material during processing of the hardness measurements results, which is estimated by the Weibull coefficient (m) (Lebedev, 2003; Lebedev et al., 2012):

$$m = \frac{d(n)}{2.30259 \cdot S(\lg(H))}, \tag{6}$$

where $d(n)$ is a parameter that depends on the number of measurements n;

$$S(\lg(H)) = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n}\left(\lg(H_i) - \overline{\lg(H)}\right)^2}, \tag{7}$$

$$\overline{\lg(H)} = \frac{1}{n} \cdot \sum_{i=1}^{n} \lg(H_i). \tag{8}$$

With a known distribution of the coefficient of homogeneity of Weibull (m) it is advisable to assess the degradation of the material structure by its technological damageability D:

$$D = 1 - \frac{m_i}{m_{matr.}}, \tag{9}$$

where mi is the value of the Weibull coefficient for the i-th cross section of the measurements; mmatr. is the value of the Weibull coefficient for a main material.

RESULTS AND DISCUSSION

We used the LM-hardness method to select a rational route of casting processing. For experimental research, the blanks were cast in a metal mold. The blank was made of material AK21M2.5H2.5 State standard-GOST 1853-93 and its dimensions were 145x60x15 mm. The casting was machined by an end-cutter on the universal milling machine of model 676. For each machining we planned two series of experimental researches. There were two variants of the technological route of blank manufacturing and following machining. The first variant included casting in a cold and warmed-over metal mold, rough milling and finishing. The second variant included casting in a cold and warmed-over metal mold, semi-rough milling and finishing. At the end the surface of the experimental sample was controlled by the measurement device (Kusyi & Stupnytskyy, 2020).

The cutting parameters were: for rough machining: cutting depth t = 1.0 mm, feed rate S_{min} = 100-120 mm/min, rotary speed n = 700 min^{-1}, cutting speed V = 26.39 m/min; for semi-rough machining: t = 0.3 mm, S_{min} = 13 mm/min, n = 1050 min^{-1}, V = 52.78 m/min; for finishing: t = 0.3 mm, S_{min} = 13 mm/min, n = 1050 min^{-1}, V = 52.78 m/min. Hardness was measured on the device TP-5006 by means of a ball ∅ 3.175 mm subjected to loading with 588.4 N. 30-35 measurements were performed in each experiment (Kusyi & Stupnytskyy, 2020).

The Weibull homogeneity coefficient (m), the technological damageability (D) was calculated by equation (6), (9) in Mathcad 15 medium using the research results. The diagrams m=f(n) and W=f(n) is presented in Fig. 4, 5 (Kusyi & Stupnytskyy, 2020).

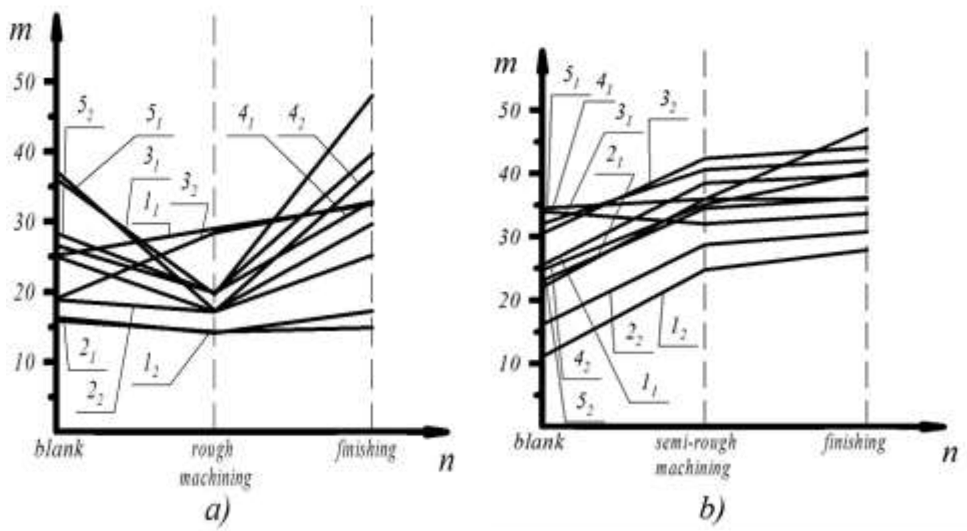

Figure 4. Change of Weibull homogeneity coefficient *(m)* in the surface layer of the casting for the first (a) and second (b) variants of the technological route (1, 2 are the castings spilled in cold metal mold, 3, 4, 5 are the castings spilled into heated metal mold; indexes 1, 2 are indicate the number of the melting blank)

The researches results demonstrate a general tendency in the formation of the surface layer of casting after pouring metal into different metal molds (see Figure 4, Figure 5). A heated metal mold has the lower level of heterogeneity development during crystallization in the conditions of decrease in the temperature field between the crystallized metal and the form to compare with a cold one. Therefore, the value of the Weibull coefficient (*m*) on the blank surface is less, and the tendency to technological damageability (*D*) is higher when pouring liquid melt into a cold mold than into a heated one.

The choice of a rational technological way of product production plays an important role for its further operation.

After rough milling for the first variant of the technological route (blank - rough machining - finishing) to a depth of 1 mm a decrease in the value of the Weibull homogeneity coefficient (*m*) and an increase in the values of technological damageability (*D*), compared to similar measurements on the surface, are found. This is explained by the growing tendency to damageability of the material in the deformation zone of the processed layer and the presence of significant residual tension after preprocessing by milling. Finish milling after preprocessing to a depth of 0.3 mm contributed to the increase in the Weibull homogeneity coefficient (*m*) and decrease in the values of technological damageability (*D*), caused by removal of the metal layer with a developed damageability during machining (see Figure 4,a; Figure 5,a).

After semi-rough machining and finish milling to a depth h_1 = 0.3 mm; h_2 = 0.6 mm for the second variant of the technological route (blank – semi-rough machining - finishing) a general trend toward increasing the value of the Weibull homogeneity coefficient (*m*) and decreasing the value of the technological damageability (*D*) compared to similar measurements on the surface is observed. In this case the dynamics of the change in the values of the Weibull homogeneity coefficient (*m*) and technological damageability (*D*) is more intensive for semi-rough milling. This is due to the removal of the defective surface layer and adjacent layers of oxides and dirt of the blank (see Figure 4, b; Figure 5, b).

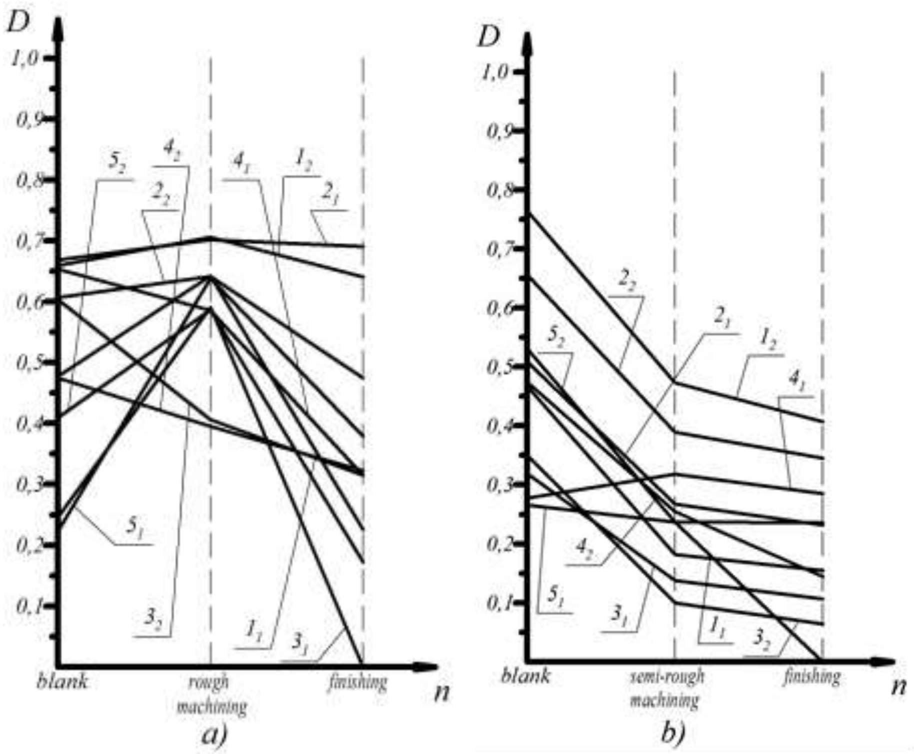

Figure 5. Change of technological damageability *(D)* in the surface layer of the casting for the first (a) and second (b) variants of the technological route (1, 2 - castings spilled in cold metal mold, 3, 4, 5 - castings spilled into heated metal mold; indexes 1, 2 indicate the number of the blank melting)

CONCLUSIONS

The main conclusions have been drawn basing on the researches results.

The technological damageability (*D*) is proposed for choosing the rational technological route of product manufacture. The technological damageability (*D*) for castings is analyzed by the value of the Weibull homogeneity coefficient (*m*) in terms of the degree of scattering of the characteristics of the mechanical properties of material.

Increase in the force loads during preprocessing machining, in particular milling, contributes to the increase of the damageability of the surface layers through the production of a gradient structure in the blanks. Reducing the energy characteristics of the cutting process in the modes of semi-finished and finished processing reduces the number of stress concentrators in the material. This provides a positive effect on the formation of the surface layer parameters and predicts the behavior of the parts during their exploitation.

Further research should be carried out for a more wide nomenclature of materials of machine products to introduce the proposed technique into the mechanical engineering practice.

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