



Creation of new technological methods for surface engineering based on broaching

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Abstract

The article is devoted to the creation of new processing technologies through the use of drawing. It is determined that the most effective processes of surface engineering of machine parts are hybrid technologies. The advantages of such technologies due to obtaining a new effect from the impact on the part by two or more dissimilar processes belonging to one or different groups of surface engineering methods are noted. It is proved that the use of hybrid technologies on the basis of stretching allows to combine the advantages of different methods, first of all cold plastic deformation methods, in combination with others. The use of deforming drawing provides in the surface layer favorable for the part of the compressive residual stresses, increase the wear resistance of the surface, as well as the strength of the part. The results of the research allowed to classify the deforming drawing as a class of surface engineering methods. On the example of processing of cylinder liners of internal combustion engines the combined technology containing operations of deforming drawing and finishing antifrictional non-abrasive processing is developed. It is shown that the use of deforming drawing has significantly improved the quality of antifriction coating. The use of deforming drawing to the component of the hybrid method with the subsequent pulsed nitriding is considered. It is established that when nitriding cutting tool products, hybrid process modes should be set in order to create the most effective nitride zone. In the case of processing of road vehicle parts, special attention should be paid to obtaining a diffusion layer. The efficiency of the offered technologies on the basis of stretching is established. Determining the prospects for further use of deforming drawing as an integral part of hybrid technologies.

Key words: surface engineering, broaching, hybrid technologies, finishing antifriction non-abrasive treatment, nitriding

Introduction

Modern machines must have a set of operational, aesthetic, environmental, technological and other properties that are determined by the indicators system of the machine quality, which in turn are provided by the properties of the surface, surface layer or individual surface of the part. This means that when choosing structural materials for mechanical engineering should distinguish between the functions of the core and the surface layer. This design and technological concept of creating machines is not only strategic but also universal, as it dominates throughout the life cycle of the machine, in particular, in its manufacture, operation and repair, as well as in the restoration of individual components and parts. The general priority of modern mechanical engineering, which includes the development of known and creation of new technologies for influencing the surface layer of the part, the purpose of which is to control the composition, structure and properties of the latter, was defined as "surface engineering of machine parts" (SE).



Literature review

There are about two hundred methods of surface engineering, which should be classified as follows: coating, modification of the surface layer, technological and combined (hybrid) methods. Currently, researchers pay the most attention to coatings that can be obtained by gas-thermal and mechanothermic spraying, vacuum-condensation technologies, surfacing, galvanic and chemical deposition, enameling, plating, cladding, hot metal coating, solid lubricants application [1]. Having a number of advantages (thickness $0.005 \div 5$ mm; high level of physical and mechanical properties; used equipment and technological equipment), coatings are still not securely held on the base, require finishing machining, create a large gradient of harmful residual stresses. Modification of the surface layer, including surface heat and chemical-thermal treatment and cold plastic deformation (CPD), is free from these disadvantages, as the means of influencing the properties of the metal are structural transformations, diffusion processes and changes in dislocation density in the base material. The disadvantage of the modification is the difficulty of managing the size of worn parts. Technological methods involve the impact on the surface layer of the part in order to change its properties by cutting or related processes. This group includes most methods of obtaining regular macro- and microreliefs. Hybrid methods involve obtaining a new effect from the impact on the part of two or more heterogeneous processes belonging to one or different groups of SE [2, 3].

Obviously, each of the methods affects the operational properties of machine parts through a set of geometric and physic-mechanical characteristics of the surface, primarily accuracy, roughness, support area, microrelief, macrorelief, porosity, hardness, microhardness, residual stresses, microstructure, texture, adhesion properties, adhesion strength to the base, the resource of plasticity used, etc. The obtained physic-mechanical and geometrical characteristics allow to increase wear resistance, corrosion resistance, fatigue strength, oxidation resistance, contact hardness, heat resistance, adhesion resistance, heat strength, antifriction or friction properties, tightness of joints, strength, lubricant retention efficiency, friction vapor compaction, heat and electrical insulating properties, fragmentation munitions efficiency, tool cutting properties.

In our opinion, hybrid technologies are the most effective processes of the surface engineering of machine parts, both in the main and in the secondary (repair and restoration) industries.

Special attention should be paid to the methods of parts finishing processing by CPD, among which should be noted deforming broaching (DB). The analysis of known sources showed that with all the variety of research in the field of DB application, despite its advantages, the use of this process requires more in-depth research, including the development of combined technologies. One of the examples of such a process is the technology of vehicle parts restoration, which includes volumetric CPD (shaping) followed by low-frequency finishing ionic pulsed nitriding [3, 4]. CPD by deposition, rolling, compressed liquid, drawing, hydroabrasive treatment, rolling, deforming broaching and stitching (mandrel) allows to obtain a number of useful from the standpoint of SE geometric and physic-mechanical characteristics of products surface layer. At the Institute of Superhard Materials named by V.M. Bakul of the NAS of Ukraine for the last few decades have been studying deforming broaching (DB) and related processes of CPD, which allowed to obtain important scientific results that formed the basis of many resource-saving technologies [5-9, etc.]. In this case, the DB was often considered as a finishing operation, the basis of which was the following [10, 11]. The accuracy of the holes in the circle, taking into account the shrinkage (+) and breakdown (-) after the DB was within ± 0.02 mm, and the curvature of the generator – 0.15-0.30 mm per 1000 mm of sleeve length. The roughness of the treated surface was guaranteed to be provided in the range of $R_a = 0.05-0.15$ μm , and the bearing surface – 90-95%. Studies have also shown that, depending on the modes of DB and the type of processed material, the thickness of the reinforced textured layer is 0.05-0.3 mm, and the degree of metal hardening in this layer is 50-300% (by microhardness index).

Thus, the analysis of literature sources showed the possibility and prospects of creating new technological methods of surface engineering on the basis of DB.

Purpose

The aim of the work is to expand the technological capabilities of DB by creating new technological methods of surface engineering to improve the quality of surface treatment.

Results

Studies [7-11] have shown that DB provides in the surface layer favorable for the part compressive residual stresses of the I kind, increase the wear resistance of the surface several times (except in the case of friction pair in abrasive wear), as well as the strength of the part. The last two effects are explained by the texturing of the surface layer, increasing the yield strength of the treated material, reducing the geometric parameters of stress concentrators and the favorable effect of compressive residual stresses.

This is confirmed by the distribution curves of some of the above characteristics of the DB surface layer, shown in Fig.1 and 2.

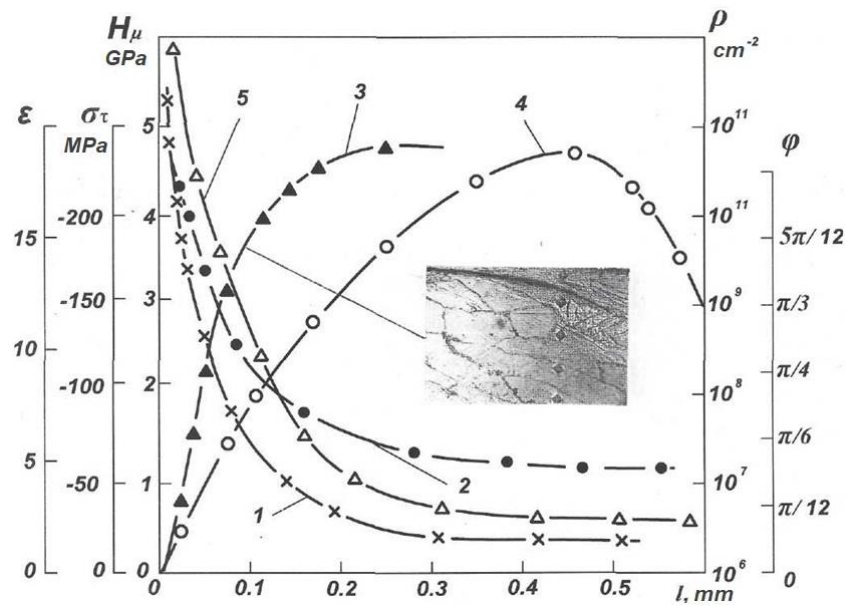


Fig. 1. Distribution of relative deformations of simple shear ε (1), microhardness $H\mu$ (2), tilt angle of texture grains large axes φ (3), compressive tangential residual stresses of the I kind σ_{τ} (4) and dislocation density ρ (5) by thickness of l linear surface layer from steel 10 processed by DB with 20 cycles.

In the center – the microstructure of the sleeve surface layer, $\times 120$

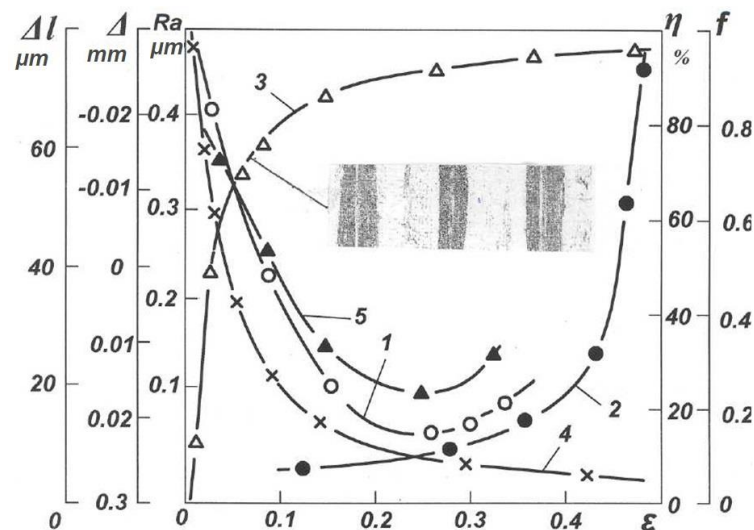


Fig. 2. Dependences of roughness Ra (1), accuracy Δ holes in a circle (2), bearing surface η (3), coefficient of friction f (4) and wear of a part Δl (5) on relative deformation ε at DB of a sleeve from steel 10. In the center – photomicrograph ($\times 80$) of the hole area with regular annular microrelief: light stripes – support platforms, dark – grooves

The above research results allowed to classify CPD with the help of DB to the class of SE methods, combined with the concept of the surface layer modification during the manufacture and renovation of products [2].

At the same time, the results of careful analysis of some other surface layer properties after DB, which previously remained out of the researchers attention, led to the conclusion that this process can also be attributed to classes of technological and hybrid methods of SE. Thus, given the technological characteristics of the DB, in particular the magnitude and smallness of deformation, can be created on the treated surface of the part micro- and macroreliefs of the desired type, shape and height of each element, as well as control the number of elements per unit area, relative bearing surface and angles. Boring, cutting or other cutting processes should be used as the pre-DB treatment. As an example, Fig. 2 shows the curve of the support surface 3 and the area of the hole with a regular annular microrelief ($\eta = 70\%$). The importance of technical solutions related to micro- and macro-reliefs is evidenced by the fact that they developed a state standard [12], defended several dissertations and published a number of monographs. We propose to use regular technological reliefs as micro-tanks for lubrication when working in sliding friction pairs of vehicles, such as power systems of hydraulic systems, shock absorbers, jacks, bearings. This protects the contacting parts from setting. For this purpose, it is advisable to use another property

of the surface layer after the DB – increasing the yield strength of the treated material by 40-70% and, as a consequence, – the allowable contact stresses by the criterion of setting bridges occurrence. This is confirmed by the curve of the friction coefficient on the level of deformation at DB (Fig. 2). This graph shows that even with small deformations, the reinforced by CPD surface receives reliable protection against adhesions (internal friction).

When using DB as part of one of the SE hybrid methods, including shape-forming CPD, followed by a finishing low-frequency ionic pulsed nitriding, the physical essence of the new joint effect on the product is as follows. When DB as a process that completes the formation of the part with the necessary increase (decrease) of its size, in the surface layer, along with obtaining the above useful geometric and physic-mechanical properties, a texture with variable tilt angle of a grain large axes relative to the movement direction of the tool (Fig. 1; curve 3; photomicrograph; $\varphi = 0 - \pi / 4$). Elongation of the microstructure grains is accompanied by their grinding and increasing the dislocations density by several orders of magnitude (ibid., curve 5). This preparation of the surface layer for further nitriding is extremely useful because it allows increasing several times the speed of this process, which is explained as follows.

The essence of low-frequency ionic nitriding in the pulsed mode, sometimes called nitriding in the glow discharge (NGD), is that in the rarefied gaseous environment between the cathode (part) and the anode (vacuum chamber wall) a glow discharge is excited. At the same time, positive ions with high energy, bombarding the surface of the part, heat it to saturation temperature and deepen into it, forming a solid solution of nitrogen in the metal, and when the solubility limit is reached – nitride phases. Pre-nitriding DB significantly accelerates the diffusion of nitrogen into the surface layers of the part, as it ensures the movement of atoms not only outside the grains of the base metal, but also mainly through the grains themselves behind dislocations. The structure of the nitrided layer consists of two zones: the outer nitride and the diffusion zone of the unsaturated solid solution with dispersed inclusions of intermediate phases [13]. The properties of the nitride zone, which has a thickness of several micrometers to several hundredths of a millimeter, are very different from the diffusion zone, the thickness of which can vary from several tenths of a millimeter to several millimeters. In the first case, the layer of material has a high hardness and fragility, and in the second – at lower hardness, the layer is stronger. Therefore, when NGD products such as cutting tools should be set modes of the hybrid process to create the most effective nitride zone. In the case of machining parts of road vehicles, a typical representative of which is the crankshaft, special attention should be paid to obtaining a diffusion layer. It should be borne in mind that the nitride zone can be a barrier to diffusion processes [14].

A promising area of further research of the described hybrid process is to obtain a duplex surface layer that would combine CPD, precision nitriding and coating application of TiN type with a thickness of $2 \div 5 \mu\text{m}$ by the KIB method.

Another example of DB using as a component of a SE hybrid method is our technology of antifriction coatings, which includes mechanical surface preparation as a basis for creating regular microrelief, friction-mechanical coating and finishing processing – by deforming broaching [15]. The essence of the proposed and the participation of the DB are as follows. As noted in [16], the quality of the coating obtained by finishing antifriction non-abrasive treatment (FANT) mainly depends on the triggering of the following channels of contact surfaces activation: mechanical, chemical, thermal and vacancy-dislocation. At the same time, the authors of [17, 18] substantiated the feasibility of forming favorable shapes and sizes of microroughness in previous FANT operations, for example, creating a regular microrelief by turning as one of the conditions for obtaining a quality coating.

It is difficult to obtain a high-quality antifriction coating on a surface with a rough regular microrelief due to the peculiarities of filling the microroughness hollows with antifriction material. Thus, voids can occur between individual particles of antifriction material, which negatively affects the density and continuity of the coating.

The use of DB will significantly improve the quality of antifriction coating, namely:

- provide the individual elements packaging of the antifriction product in a solid mass and strengthening the coating material with the base by surface plastic deformation;
- increase the strength of antifriction material adhesion to the base;
- create a microrelief with a greater bearing capacity of the surface.

The proposed technological solution formed the basis of our developed technological process of processing the hole in the ICE sleeves using combined broaching and FANT [19, 20].

At the combined broaching there is a removal of an allowance by a cutting element and increase in the size of a hole by group of deforming elements. As a result of processing, the rough layer of the sleeve working surface has the necessary physic-mechanical and geometric properties. The change in the height parameter of the roughness R_a and the microrelief of the working surface during sleeves processing by FANT and DBR is shown in Fig.3.

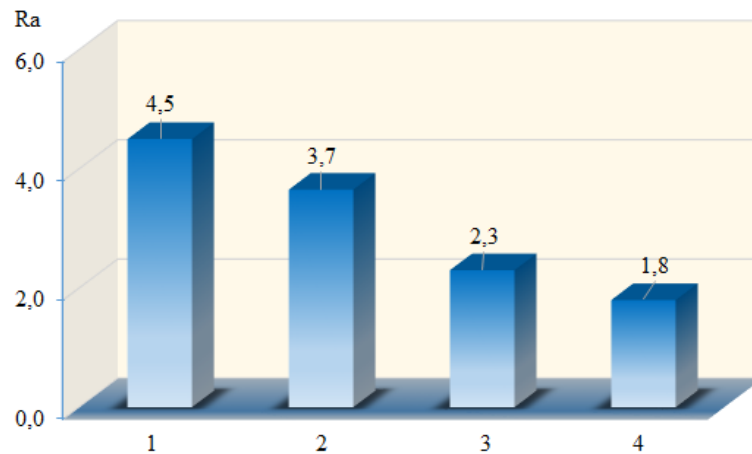


Fig. 3. Changing the parameter Ra when processing the sleeve: 1 – boring; 2 – FANT; 3 – DB with one deforming element; 4 – DB by two deforming elements

The use of DB allowed reducing the parameter Ra and creating a new technology for applying antifriction coatings using DB [21].

Conclusions

The application of the proposed hybrid technologies based on broaching allows to combine the advantages of different methods, including surface modification and coating application with the achievement of higher operational properties of parts that require further study.

The technological process of ICE sleeves processing has been developed, which includes operations of DB and FANT, which provides the obtaining of the sleeve working surface with improved physic-mechanical and tribological characteristics. The efficiency of the combination of DB and FANT operation has been established, which allows improving the quality of ICE sleeves processing.

The technology of details restoration containing DB with the subsequent finishing low-frequency ionic pulse nitriding is offered.

Determining the prospects for further research of DB as part of hybrid technologies.

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Шепеленко І.В., Посвятенко Е.К., Немировський Я.Б., Черкун В.В., Рибак І.П. Створення нових методів інженерії поверхні на основі протягування

Стаття присвячена створенню нових технологій обробки за рахунок застосування протягування. Визначено, що найбільш ефективними процесами інженерії поверхні деталей машин є гібридні технології. Зазначено переваги таких технологій за рахунок отримання нового ефекту від впливу на деталь двома або більше різнорідними процесами, що належать до однієї або різних груп методів інженерії поверхні. Доведено, що застосування гібридних технологій на основі протягування дозволяє поєднувати переваги різних методів, перш за все методів холодного пластичного деформування, у поєднанні з іншими. Розроблені комбіновані технології обробки, що вміщують деформуюче протягування і фінішну антифрикційну безабразивну обробку, також деформуюче протягування з наступним фінішним низькочастотним іонним імпульсним азотуванням. Встановлено ефективність запропонованих технологій на основі протягування.

Ключові слова: інженерія поверхні, протягування, гібридні технології, фінішна антифрикційна безабразивна обробка, азотування.