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Surface Layer Formation at Dynamic Combined Exposure by Two-Component Electrode

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Abstract. This article is devoted to the study of workpieces surface layer state, resulting from dynamic exposure of a two-component electrode with imposition of electric field. The objects considered in the work are details with complex profile. Such parts are used in aviation, rocket and space technology and in oil and gas industry. They include impellers and flow part of turbopump bodies, augers, blade wheels, which have areas of variable curvature with limited tool access to treatment area. The authors show that mixture in combined process of two-component processing media from current-carrying granules and conductive liquid medium supplied at high speed to the treatment area, provides the required quality of surface layer due to the combined dynamic exposures on the material being treated. The parameters combination of electric field and kinetic energy of conductive granules allows you to control the magnitude and depth of material hardened layer in treatment area. Experimental studies have shown the increase in resource and durability of critical assemblies for aerospace equipment and oil and gas apparatus.

1. Introduction

The work of critical parts under conditions of intensive alternating loads forces us to improve technological processes that increase operational characteristics of products. The problem of ensuring the quality of surface layer on critical parts and assemblies of aviation, rocket and space as well as oil and gas transmission equipment is acute and requires its solution. In mechanical engineering, methods of electrochemical mechanical processing are used for a long time, they provide microprofile of the surface to be processed using unbound conductive granules as a tool [1-4]. However, the increased requirements for such details make it necessary to conduct research on the management of surface layer forming process at the level of nano-values. Special attention should be paid not only to the conditions of working medium flow and surface formation mechanism [3, 5], but also to the known connections between properties of surface layer material and product performance characteristics [3, 6-9]. Therefore, the aim of the authors' work was the development of modes and methods for combined processing, providing at nano-level directional transformations of workpieces materials properties during combined processing [3]. The main idea of the process was the interconnection of hydrodynamic, electrical parameters of the process with prediction of surface layer state of material, which ensures surface roughness of not more than Ra = 320-630 nanometers (depending on the type of material being processed and the processing mode).

2. Mechanics and dynamics of surface layer formation

All known combined processing schemes with application of two-component working environment are intended for finishing operations of forming workpiece surface layer. This corresponds to the stage of technological process, when formation of processed surface quality characteristics, also at nanoscale level, takes place. Solid conductive granules placed in the liquid phase of technological environment are a tool, that having significant kinetic energy, reduces surface asperities and produces internal microstresses. These factors are decisive in formation of workpieces service factors. Wear resistance, strength, resistance to fatigue and alternating loadings directly depend on the state of surface layer, namely on surface roughness index and its physical and mechanical properties [10-13].

3. Research methods used by the authors

The state of surface layer was studied by the standard method on transverse microsections treated in the modes used for workpieces manufacture. Microsections were subjected to chemical treatment and etching to identify material structure and their further study by optical and electron microscopes. In addition, microhardness was measured on samples at location of near surface layer with modified structure and hardness by introducing indenters on oblique sections.

The surface layer state was investigated for the case of all technological factors impact according to the schemes:

- with anodic dissolution of workpiece surface and its subsequent plastic deformation by solid component of working environment;
- with anodic dissolution of workpiece material with hereditary layer removal and the simultaneous surface hardening by solid component of working environment.

The surface state after processing was evaluated according to several characteristics: material structure at nanoscale level, irregularities height, effect of granules on the surface layer state.

4. Research results and their interpretation

The authors found that filler motion parameters and its physicomechanical properties have the greatest influence on the process of forming workpiece surface layer at micro and nano levels. Metallographic studies revealed that samples had a modified layer with the depth from 4 to 12 microns with a maximum cold work directly at the upper boundary of this layer [14-16]. Microsections photographs of the samples examined «before» and «after» processing are shown in figure 1. Various materials with different hereditary surface layers were processed. In addition, the conditions and modes of treatment were modified.

A sample of 40CrNi2MgA steel (figure 1, a and b) was obtained by rough milling and subjected to electrochemical mechanical processing (EChMP) at more “hard” modes: filler granules were made of steel 45 of size d = 5 mm; concentration in interelecrode space was 25 - 30%; the electrolyte was 15% solution of NaCl; the granule feeding scheme gave them high kinetic energy of about 10 m/s (calculated value); operating voltage on electrodes was 75 V; the total distance from the hydraulic element to the workpiece surface was 50 mm; processing time, as in the previous case, was 40 s.

The microsections photographs (figure 1) at nanoscale level clearly show the uniform modified surface microlayer of metal, which is characterized by more dense arrangement of material grains. Microhardness measurement showed its increase due to mechanical effect of the filler to the value of 43.5 HRC, which is higher than that of the raw stock, where this figure is 35.5 HRC. The change in microhardness of workpiece surface layer proves that internal and - as we have established - compressive microstresses are formed in it. At boundary, maximum possible with the used processing schemes and equipment, processing modes (photographs in figure 1; 2, a, b), the amount of cold work was $U_n \approx 22.5$ % with total depth of $h \approx 10$ micron. Maximum cold work is observed at its upper boundary.

The sample presented in figure 1, c and d, was made of steel 38Cr2MgAlA, its previous machining operation was finishing milling. When processing it, “soft modes” were used: the diameter of filler

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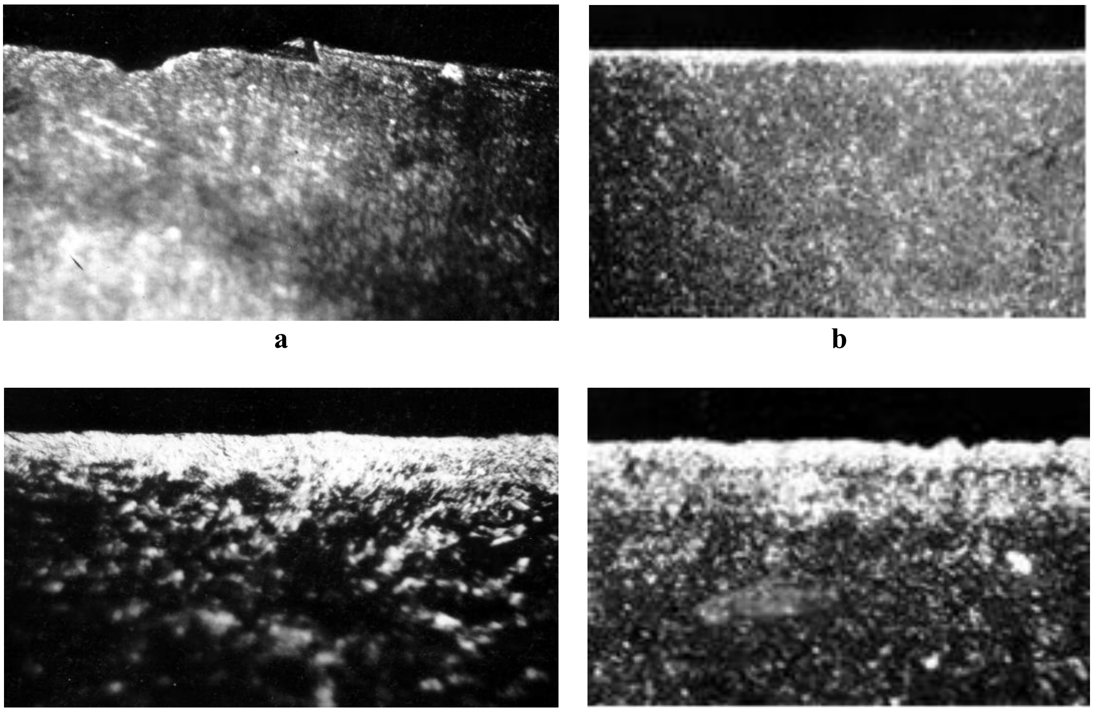
granules, made of the most common steel 45, was 5 mm; their concentration in the total volume of working environment was 25–30%; fifteen percent sodium chloride solution NaCl was used as electrolyte; granules were fed to treated surface with rated speed of 5 m/s; operating potential on electrodes was 50 V; the size of interelecrode space was 50 mm; the processing time for workpiece area equal to the effective spot was 40 s. Microsections of this sample reflect the presence of hardened layer with the depth of $h_n \approx 4.5$ microns and $U_n \approx 13.5$ %. On the workpiece surface there are no microcracks and micro-etching at grain boundaries in the hardened layer. This indicates the presence of compressive residual stresses, which increase fatigue strength of the workpiece. The performed measurement of microhardness showed that, in contrast to the unchanged state (34.5 HRC), it increased due to processing to the value of 39.5 HRC.

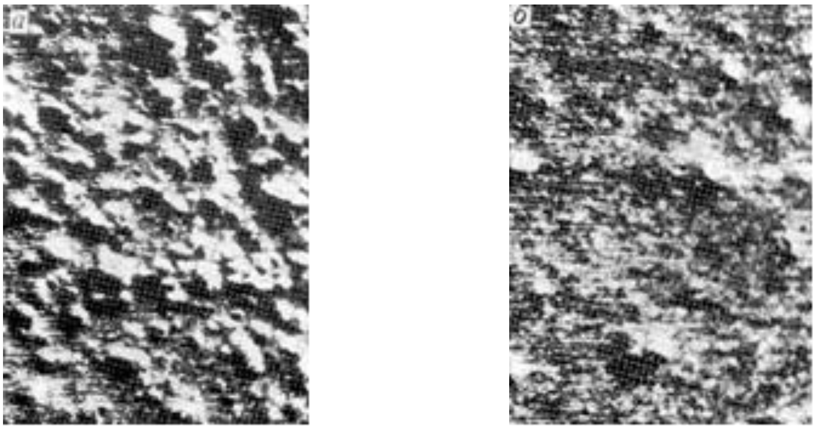


a **b** **c** **d**

Figure 1. Research Results for Surface Layer of the Workpiece Subjected to Electrochemical Mechanical Processing with Filler Usage and Electric Field Application: **a** - steel 40CrNi2MgA before processing; **b** - steel 40CrNi2MgA after processing; **c**, **d** - steel 38Cr2MgAlA after processing

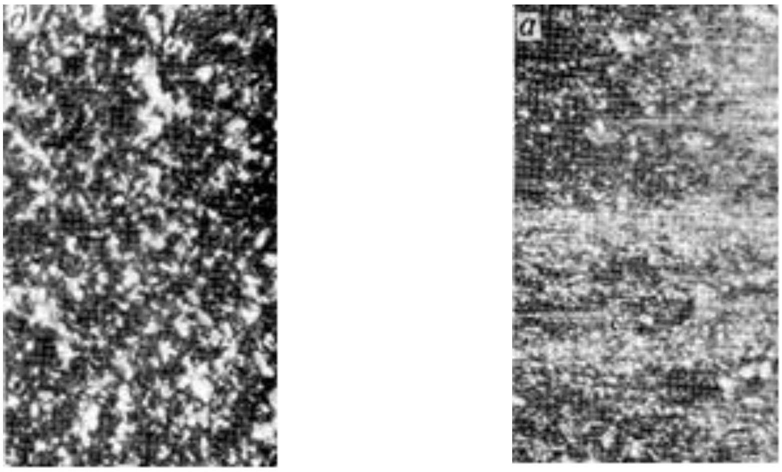
For visual assessment of results for combined treatment with two-component working media, the study of the outer surface of the samples, previously characterized at various values of interelectrode gap, was made. Photographs of the outer surface of samples from steel 38Cr2MgAlA are shown in figure 2. In figure 3 you can see the appearance of samples surface of steel 40CrNi2MgA, obtained by changing interelecrode space size from 40 to 70 mm, other technological processing conditions during the experiment were not changed.

After analyzing figure 2 and 3, the authors concluded that at processing with filler there is no etching on the grain boundaries of workpiece material. Slight decrease in workpiece surface roughness at increase of interelectrode gap can be explained by decrease in amount of total energy of working medium taking part in shaping. Similar experiments were carried out for other processed materials.



a **b**

Figure 2. Microsections of Samples from Steel 38Cr2MgAlA after EChMP at Various Values of Interelectrode Space: **a** 35 - 40 mm; **b** 70 - 75 mm



a **b**

Figure 3. Microsections of Samples from Steel 40CrNi2MgA after EChMP at Various Values of Interelectrode Space: **a** 40 - 42 mm; **b** 70 - 71 mm

5. Practical Application of Results in Industry

The performed studies of surface layer state at nanoscale made lodgment for applicability of the treatment process with two-component working environment for workpieces surfaces (figure 4) containing areas which are difficult to reach (and in some cases inaccessible) for a profile tool with obtained roughness of less than 300 nanometers.

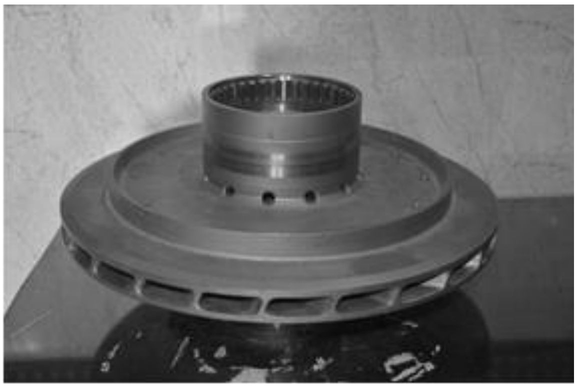


Figure 4. Turbopump Assembly Rotor with Limited Tool Access to Blade Channels

Figure 4 shows the impeller of turbopump assembly from heat-resistant alloy with channels of complex geometric shape, where at the finishing stage our method [1; 2] provides increased operating characteristics: low hydraulic resistances to the flow of gas-liquid media; resistance to damage at high peripheral speeds; wear resistance and stability of indicators when working with high pressure of transmitted stream.

6. Conclusions

The main results are the following:

- the authors have confirmed some elements of nanotransformations theory and the method of dimensional shaping by complex effect at nanoscale level using two-component working medium that provides electrochemical dissolution of nanolayer allowance when using unbound conductive granules as a tool;
- the effect of dimensional combined treatment process with the filler on the change in nanostructure of workpiece surface layer is substantiated, it ensures the achievement of required quality indicators for the surface layer and increase in operational characteristics;
- the authors created conditions for implementation of dimensional shaping in workpieces with complex geometry at control of the process for obtaining surface layer characteristics, this expands technological capabilities of the method under study;
- the relevance and novelty of new methods of combined processing were confirmed (Russian patents).

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