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Ultrasonic impulse reinforcing finishing of metals as a new methods using a nanomaterial for surface of machines elements

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Abstract: *Ultrasonic impulse reinforcing finishing of metals as a new methods using a nanomaterial for surface of machines elements*. The article is devoted to the advantages and features of the plastic deformation of surfaces of parts, as well as a method of forming a wear-resistant coating, by applying the repair compositions of nanomaterial on their surface, followed by plastic deformation. The value of the research is to show a new method to obtain a novel properties of surface with a better physical and chemical properties.

Key words: nanomaterial, plastic deformation, ultrasonic impulse, finishing of metals

INTRODUCTION

The most important things and challenges which stay in front of scientists, designers and technologists in the changeable technical environment is to find the best solution of the problem connected with increasing working limit and working limit of parts, which are comprised in machines and gears.

The quality of a product is one of the basic elements taken into consideration in the product constructions and evaluations. One of the main aims of the quality system in a factory or manufacturing company is making provision for good planning of actions directed to quality stabilization on a good level [Buliński and Łyp-Wrońska 2014].

One of the meanings of the quality in a factory is the quality of surface layer. This quality is one of the most important factors determinant longevity of machines and mechanisms. The surface of mated parts is bearer of residual macro and micro stresses, wear macro and micro deformation, embedded abrasive and other defects by using popular methods of materials processing. In order to increase durability and wear resistance of parts it is necessary to apply processing, which will improve physical feature, structure and micro geometry of surface.

The following classical the most popular methods of quality improvement are known:

- *shot peening*: a cold working process used to produce a compressive residual stress layer and modify mechanical properties of metals and composites. Shot peening is a method widely used to improve mechanical properties of materials. The improvement in mechanical properties such as surface hardness, fatigue strength, tensile strength, damping etc. are due to the induction of compressive residual stress in the metal parts. The residual compressive stress induced by shot peening is the function of material and mechanical conditions. Its beneficial effects are mainly due to the residual stress field caused by the plastic deformation of the surface layer of material resulting from multiple impacts of the shot, although strain hardening and grain distortion caused by the multiple impacts of the shot also play a role in the modified mechanical behaviour of the peened components. Due to several advantages shot peening has been in the focus of research persons for the purpose of increasing the properties of the materials [Hetram et al. 2015]. Results of shot-peening: micro hardness of surface increases insignificantly, surface asperity almost doesn't reduce, wear durability increases by a factor of 1.5 and more;

- *burnishing by ball*: type of machining, the purpose of which is to strengthen the surface layer of parts, increasing its durability and achieve quality class. Surface quality is an important factor to decide the performance of a manufactured product. Quality of surface affect product performance [Ghodake et al. 2013]. Results of burnishing by ball: micro hardness of the surface increases in 40–60%, asperity reduces approximately from 5 to 10 class, it's usually required to make some passes of instruments along part, cold-hardening with significant thickness is constituted;
- *broaching*: a machining process that uses a toothed tool, called a broach, to remove material. The broaching process may be used to generate irregular internal and external part features, and therefore has many potential industrial applications [Cholpadi and Kuttan 2014]. There are two main types of broaching: linear and rotary Results of broaching: micro hardness of the surface increases in 25–35%, asperity reduces approximately from 5 to 9–11 class, insignificant cold--hardening up to 1 mm;
- *reinforcing by shock wave*: this method is suitable for materials which are difficult to produce using traditional processes. because of high reactivity of materials [Tong et al. 1995]. Results of reinforcing by shock wave micro hardness of the surface increases in 60–70%, cold-hardening thickness can be up to 40–50 mm, that isn't obtained by any other methods, but it's applying is associated with well-known technological difficulties and isn't always possible.

MATERIAL AND METHODS

In the technology of improving of the surface there are some main methods: one of the promising method is ultrasonic impulse reinforcing finishing. The research has been realized as the laboratory test, using ultrasonic instrument – Ultrasonic set I-4, for cylindrical details manufactured by “Ultrasonic technique – INLAB” Sankt Petersburg. Ultrasonic set I-4 consisted of:

- ultrasonic generator I-10-0.63;
- power output was 630 W;
- graduated turning of the output power, 50, 75, 100% of the nominal output power;
- working frequency was 22 kHz ±10%;
- power supply 220V, 50 Hz;
- ultrasonic instrument, clipped into cutting holder of lathe, base of instrument – magnetostrictive ultrasonic transducer with changing instrument-indenter;
- three changing indenters;
- connecting cable with length 4 m; passport for ultrasonic generator and passport for ultrasonic set I-4.

Currently, one of the most promising areas of the surface modifying products, it is to provide for a composite material with properties different from those of the base material. This layer should provide the optimal conditions interaction surfaces under these conditions pairing operation. Various technologies are used for modifying surface layers which comprise conventional and innovative processes and methods [Muller et al. 2014].

One of the methods is ultrasonic impulse reinforcing finishing which can make the surfaces of machine parts with the best quality. Ultrasonic method is a non-destructive way to achieve the best level of surface [International Atomic Energy Agency 1999]. The use of this processing can improve the wear resistance, cyclic durability, contact fatigue and significantly reduce the surface roughness, which is one of the main factors determining the performance advantages of machine parts.

According to Chizhakov [2017] the first information and data about this method of processing appeared in works of Muhanov in 1964. At the present time in Russia equipment for this method of processing are manufactured by some companies. Significant progress in this sphere has “North-West Center of Ultrasonic Technologies” under the direction of Holopov Y. Another name of this processing method is “Abrasive-free finishing of metals” – BUFO (Russian name of method) [Chizhkov 2017]. The scheme of using this method is at Figure 1.

Ultrasonic impulse reinforcing finishing is used after lathe finishing. After ultrasonic processing of materials, nanostructured near-surface layers emerge [Astashev and Krupenin 2016]. The ultrasonic tool is fastened to cutter holder of universal lathe, under the impact of static force created by pressure and dynamic force created by ultrasonic system of oscillation (ultrasonic generator) which allows to achieve plastic deformation of surface layer of parts, increases micro hardness, removes residual macro and micro stresses, smoothes surface roughness and in total constructs

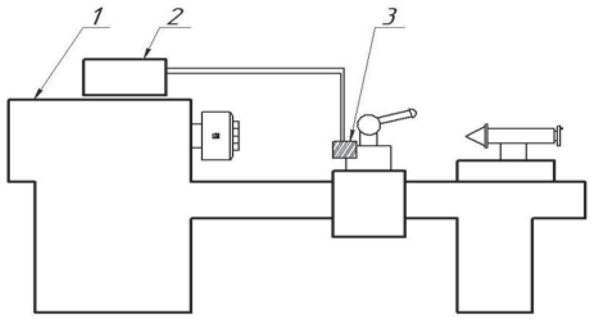

FIGURE 1. Ultrasonic instrument on a universal lathe: 1 – universal lathe; 2 – ultrasonic generator; 3 – ultrasonic instrument

improved surface layer with regular disposition of micro relief.

The scheme surface plastic deformation by ultrasonic hardening treatment is at Figure 2.

Figure 2 shows us which parameters the tool has and how the surface looks like when it is working.

The parameters are:

- form and the radius *r* of the working part of the tool (the spherical part of the tool) [mm];
- amplitude of fluctuations of indenter 2*A*;
- the value of the tool clamping force to the workpiece P_{cm} [kg];
- the value of the dynamic effects of *P* [N];
- supply of *S* [mm/rev.];
- the radius of the working tool *Sv* [mm];
- Diameter of detail *D* [mm];
- linear circumferential speed *V* of workpiece [m/min];
- moving the workpiece *Tor* (Torque) [N].

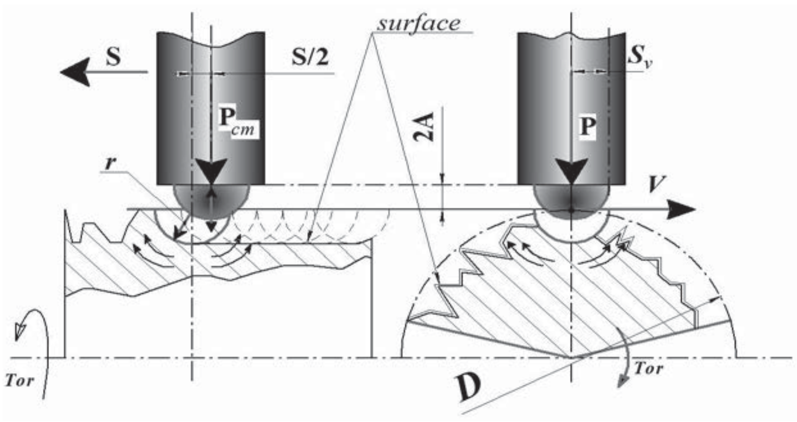

FIGURE 2. Plastic deformation by ultrasonic hardening treatment

It is also seen that when the tool forms a surface hardening (It is shown by the arrows in detail). Also, the metal removal does not occur as in grinding. This effect is clearly seen in Figure 3.

The results of applying this method for improving the surface layer of details combine the best values of single classical methods of processing of surface [Chizhkov 2017]:

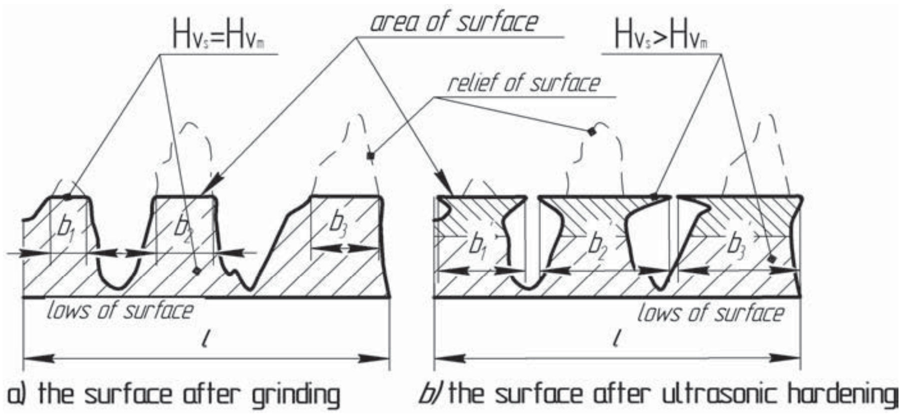

FIGURE 3. The surface after treatment

On Figure 4 we can see that after the ultrasonic hardening on the surface of part formed the cold-hardening and increases the area of surface b_1, b_2, b_3. Additionally, the hardness of surface is higher than the hardness of the material bases, Hv_s – surface hardness; Hv_m – the hardness of the main parts.

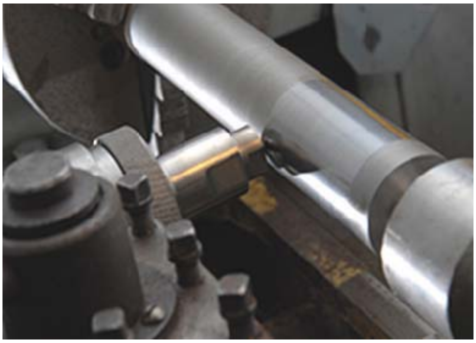

FIGURE 4. The surface after ultrasonic hardening

- micro hardness of surface depending on initial and kind of metal increases in 300%;
- asperity reduces from 5 to 9–14 class, this quality of surface can be obtained not only at thermal treated and crude steels, but also at cast-iron, non-ferrous and stainless metals and alloys;
- cold-hardening thickness may be up to 0.1mm, in single cases it's possible to realize mode of cold forging with cold-hardening thickness up to 15–20 mm;
- by optimum combination of static and dynamic forces of ultrasonic treatment it's possible to increase fluidity limit of metal and thus make a correction of part geometry;

- limit of contact persistency increases in 10–20%;
- absence of embedded to surface grains of abrasive increases up to twice working limit of mated parts (sliding pairs, impermeable glands, packing glands), possibility of producing details for food industry (for example batchers) and any machines and gears, where availability of abrasive in technological zone is inadmissible appears due to ultrasonic treating;
- regular micro relief increases property of detention oils and greases by treated surface;
- regular micro relief extra reduces wear for reciprocal movement of mating parts;
- corrosion resistance of treated surface increases.

As a result of the aforementioned properties, machine parts and mechanisms subjected by ultrasonic hardening, have greater wear resistance, cyclic durability, contact fatigue, than after grinding, burnishing by ball and many other final methods of finishing of surface of parts.

RESULTS AND DISCUSSION

Ultrasonic impulse reinforcing finishing of metals as a new methods using a nanomaterial for surface of machines elements. Nanotechnology demands the ability to control features at the nanoscale (10^{-9} m), and a variety of techniques have been developed recently that give technicians this ability. Many of classical distinctions between mechanics, materials and physics disappear in this range of length scales, and a new kind of thinking emerges that is commonly called nanoscience. The recent rapid development of nanoscience is the result of a new-found ability to observe and control structure at small length and time scales, coupled with the development of computational capabilities that re most effective at small scales [Ramesh 2009].

The method utilized in the research is that before using the ultrasonic impulse reinforcing finishing, we will apply a nanomaterial to the surface of the part and then to carry out a surface treatment by the ultrasonic hardening. The scheme of applying ultrasonic impulse reinforcing finishing using a nanomaterial is at Figure 5.

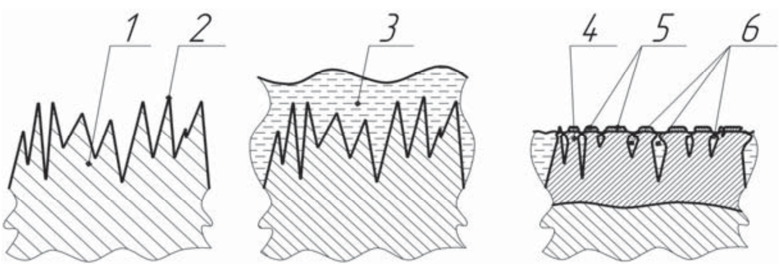

FIGURE 5. Ultrasonic impulse reinforcing finishing using a nanomaterial: 1 – the main detail; 2 – original surface on the main detail; 3 – nanomaterial (nanopowder); 4 – ultrasonic hardening; 5 – wear layer of nanopowder; 6 – surface-filled pores

Nanotechnology is design, fabrication and application of nanostructures or nanomaterials, and the fundamental understanding of the relationships between physical properties or phenomena and material dimensions. Nanotechnology also promises the possibility of creating nanostructures of metastable phases with non-conventional properties including better conditions for surface of metal [Cao 2014].

CONCLUSIONS

The research was realized under laboratory conditions utilized the ultrasonic impulse reinforcing finishing using a nanomaterial. The next step should be realized in a macro scale in the factory under real condition.

To confirm our assumptions from laboratory level it is necessary to conduct complex activity concerning the qualitative composition of the treated surfaces of various materials, and analyze their dependence on nanopowders concentration in solutions applied to the surface before using ultrasonic hardening.

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Streszczenie: *Nowe metody ultradźwiękowego wzmacniania szlifowanych metali z wykorzystaniem nanomateriału na powierzchni elementów maszyn.* Artykuł omawia nowe metody, ich zalety i cechy, dotyczące uplastycznienia powierzchni materiałów, jak również sposobu wytwarzania powłoki odpornej na zużycie przy zastosowaniu kompozycji naprawy nanomateriałów na ich powierzchni, a następnie przez poddanie odkształceniom plastycznym. Wartością zaprezentowanych badań jest pokazanie nowej metody, która pozwala na uzyskanie powierzchni o nowych i lepszych właściwościach fizykochemicznych.

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