Ultrasonic Preparation of Coating Surfaces

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Abstract. For various methods of obtaining coatings, the general stage of technology is the preparation of the surface for the application of the coating material. The properties of the resulting coating directly depend on the quality of preparation. In the process of obtaining coatings, the most common application of ultrasonic treatment to clean the surface from all kinds of contaminants. However, with a sufficient intensity of processing, ultrasound has a significant effect on the geometric properties of the surfaces of products. Prolonged cavitation action leads to changes in the roughness and sub-roughness of the metal surface. The article discusses the effectiveness of the use of ultrasonic liquid treatment in the preparation of surfaces for coating. The results of studies on the effect of cavitation on the change in roughness, sub-roughness and oil absorption are presented. Revealed an improvement in the adhesion properties of surfaces after ultrasonic liquid treatment.

Introduction

The use of ultrasound in the technological processes of material processing has become widespread in various industries. The impact of ultrasound on gaseous, liquid, solid and multiphase media creates effects that can change the structure and properties of processing objects [1]. The transmission of high-frequency vibrations to liquids, gases and dispersed systems causes a number of unique physical phenomena in them, which are widely used for cleaning and degreasing surfaces, emulsifying and dispersing materials, spraying liquids, etc.

One of the areas of application of ultrasound in industrial technologies is the creation of various coatings. There are many methods of obtaining coatings in modern industries: from the simplest, such as painting with a roller or brush, to the most complex, requiring the use of high-tech equipment and the use of the latest expensive materials [2].

Coating is intended to protect a product or a specific part of it exposed to corrosive environments, high temperatures, friction, shock loads - from the aerospace and automotive industries to biomedical devices and implants inside the human body [3].

Despite the fundamental differences in the methods of obtaining coatings for most of them, the main stages of technology are common: manufacturing and preparation for the application of the coating material; product surface treatment and preparation; coating [4, 5]. The properties of the resulting coating directly depend on the quality of each of these stages. This article explores the application of ultrasonic vibrations to prepare surfaces for coating.

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Preparation of surfaces for application of coatings consists in ensuring its industrial cleanliness, as well as creating geometry and microgeometry that are most suitable for a particular coating. Carrying out these measures is intended to increase the adhesion properties and improve the surface wettability.

Cleaning is the process of removing various types of impurities from the surface. The most common contaminants are grease, dust, scale and oxides.

In production, stubborn contaminants are particles of materials and acids formed as a result of abrasive processing (technological heredity), as well as particles of shavings and oil contamination.

Abrasive processing of most construction materials is accompanied by caricature of the surface being brought to the surface by the abrasive grain, i.e. the introduction and fixation of abrasive grains and chips in the treated surface [6].

The presence on the surfaces of products of abrasive particles of a wide range of sizes (from thousandths to thousands of micrometers) leads to an increase in friction and, as a consequence, to increased wear of friction pairs, a violation of the sealing of joints, a change in the throughput of channels, etc.

During processes associated with abrasive processing, complex technological contaminants are formed on the surface, including:

-contaminants with low relative adhesion to a metal surface and representing a complex mixture of organic and inorganic substances, saturated with abrasive particles and small metal shavings;

- contamination, which are caricatured particles of abrasive, mechanically firmly associated with the finished surface of parts.

It has been established that ultrasonic cleaning of surfaces has undeniable advantages over other cleaning methods [7, 8, etc.]. The unique effects created by ultrasound in liquid media contribute to the hydrodynamic effect on the cleaning solution and dirt. The main effects are considered to be oscillations and collapses of cavitation bubbles, microjets, microflows and shock waves [8]. However, in addition to removing contaminants, these effects lead to a change in the geometric and physical-mechanical properties of the surface of products. As a result of ultrasonic treatment, the surface layers of materials change the structure, internal stresses, hardness, roughness and sub-roughness [9].

These changes directly affect surface preparation for coating.

Adhesion, i.e. the bond strength of the substrate and the coating is one of the main properties that determine the performance of the coating.

As is known [10], the force G required to peel off the coating from the substrate:

$$G = G_0 + \psi, \tag{1}$$

where G_0 - adhesion;

ψ - energy dissipation.

The amount of adhesion is determined by the ratio:

$$G_0 = G / A \quad , \tag{2}$$

where A – contact area between coating and substrate.

In the case of using formula (2), the geometric surface area is usually taken as A without taking into account roughness and sub-roughness. However, as studies show [11], micro and submicrogeometry of the surface have a significant effect on adhesion. Since with an increase in the number and height of microroughnesses, the actual surface area increases, the adhesion of the coating also increases. Thus, an increase in roughness contributes to an increase in the quality of the coating [12, 13].

Research methodology

For experimental studies, a magnetostrictive ultrasonic oscillatory system with an operating frequency of 22±0,1 kHz was chosen. A stepped concentrator was used as a working tool, since this design provides the greatest transformation ratio of oscillations. The ratio of the diameters of the concentrator steps was 3, respectively, the transformation ratio was 9. The choice of the working tool was based on the need to ensure the amplitude of oscillations of the working surface of the emitter not less than 30 ... 40 microns.

The studies were carried out on plates made of normalized steel 3, 30x30 mm in size, 3 mm thick. The samples were ground until a roughness of Rz = 2.5 micrometers was reached. The choice of roughness is based on the requirements for painted surfaces in accordance with GOST 9.032-74. After that, a model contamination was applied to some of the samples.

Ultrasonic treatment was carried out according to the following scheme (Fig. 1).

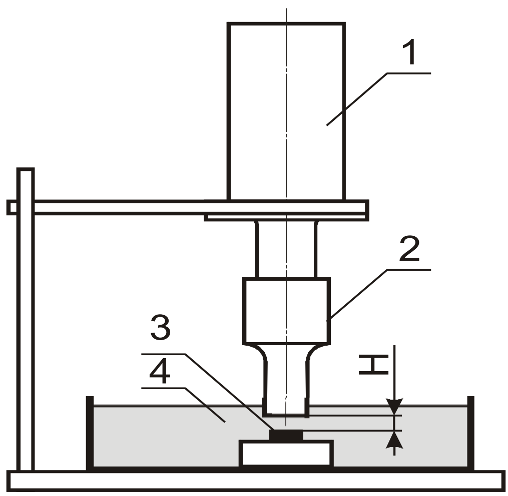


Fig. 1. Experimental setup diagram. 1 – oscillatory system, 2 – work tool, 3 – workpiece, 4 – liquid

Sample 3 was located in liquid 4 at a distance H from the working surface of the emitter 2 of the vibrational system 1. Distance H was chosen within 3 ... 5 mm to ensure the maximum effect of cavitation. Tap water was used as a liquid. Since during the operation of the oscillating system there is a strong heating of the liquid, the temperature in the working zone was maintained in the range of 25 ... 40°C.

After processing, the properties of the obtained surfaces were studied in three directions:

- surface cleanliness assessment;
- determination of microgeometric and submicrogeometric surface properties;
- measuring the adhesion of the paint coating applied to the prepared surface.

Surface cleanliness was assessed visually and using atomic force microscopy.

Part of the samples after abrasive treatment was scanned with an atomic force microscope, which made it possible to detect the presence of the smallest particles on the surface.

Samples with model contamination were cleaned using a laboratory microscope. At x6 magnification, the surface was carefully examined for contamination. Re-cleaning was carried out if there were any foreign particles or noticeable discoloration on the sample.

A layer of paint and varnish material was applied to the cleaned surface by pneumatic spraying. The adhesion of the paint-and-lacquer coating was evaluated using a mechanical adhesion meter according to GOST 32299-2013 (ISO 4624:2002 Paints and varnishes - Pull-off test for adhesion).

Results and its discussion

In fig. 2 shows the dependences of the duration of cleaning on the amplitude of oscillations ξm of the emitter when cleaning parts from model pollution and caricatured particles [14]. For ease of comparison, cleaning times are given in relative units:

$$\tau' = \frac{\tau_i}{\tau_{min}}, \quad (3)$$

where τi - duration of cleaning at a certain value of the displacement amplitude ξm; τ_{min} - minimum duration of cleaning in the studied range of displacement amplitudes.

When cleaning from cavitation-unstable model pollution, the efficiency of high-amplitude ultrasonic cleaning is determined by the action of collapsing and pulsating bubbles carried by powerful acoustic streams. The deceleration of the process of ultrasonic cleaning from model contaminants with an increase in ξm > 12 micrometers, is due to the fact that the cavitation region is localized at the surface of the emitter, and the dimensions of the parts to be cleaned exceed the dimensions of such a zone.

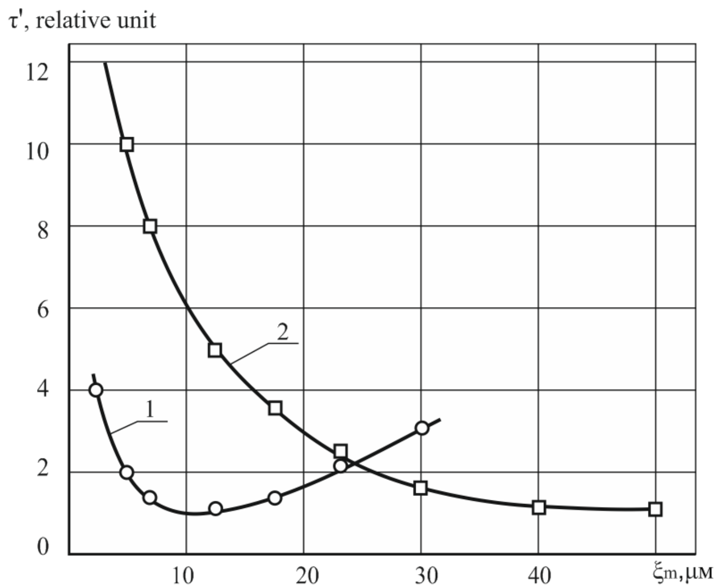


Fig. 2. Duration of cleaning from the oscillation amplitude of the emitter ξ: 1 - when cleaning from model contaminants; 2 - when cleaning from caricatured particles

The shock effect created by cavitation not only contributes to the removal of contaminants from the surface of products during processing, but also causes deformation and destruction of the surface, i.e. leads to changes in the surface properties of the processed material [14].

According to studies [15], the stages of ultrasonic cavitation impact on the surface of products can be represented as the following diagram (fig. 3).

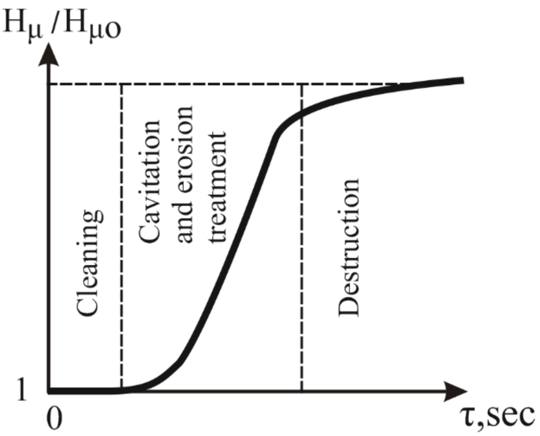


Fig. 3. Stages of ultrasonic liquid treatment on the surface of products ($H\mu / H\mu_0$ - reduced microhardness; τ - time of processing)

At the first stage, corresponding to a time of 10 ... 15 minutes, no change in the properties of the surface layer is observed. This time interval is most suitable for the cleaning operation. The work of cavitation is mainly used to separate impurities.

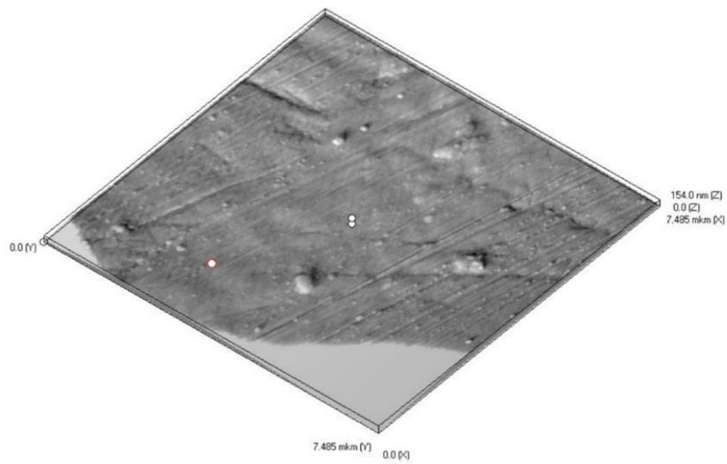
With an increase in the processing time (up to 30 ... 35 min.), Internal stresses, created by the effect of cavitation, gradually accumulate in the material. Signs of cavitation effects appear on the surface: the surface roughness begins to increase. Due to the small size of the working bodies (cavitation bubbles) and the small values of the local loads created by them, the control of changes occurring on the surfaces of the products can be regulated and dosed.

At the third stage, the destruction of the surface layer occurs, i.e. erosion itself.

Thus, the second stage is recommended for preparing the surface for coating. During this stage, not only is the removal of dirt residues, but the actual surface area also increases due to microdeformations of the surface layer.

A typical example of the use of ultrasonic treatment of the surface of an article for coating is the following. A sample of normalized steel 3 was subjected to abrasive treatment, after which a model contamination was applied to it (Litol).

The sample with the deposited contamination was immersed in water and subjected to ultrasonic treatment with a frequency of 22 kHz and an oscillation amplitude of the emitter ξ=20 micrometers. Within a short period of time (3 ... 5 minutes), the model pollution was completely removed. Over the next 20 ... 25 minutes. the surface was cleaned of caricatured particles of abrasive material, in addition, there was a change in the microgeometry and submicrogeometry of the surface. Surface images before and after processing are shown in fig. 4.



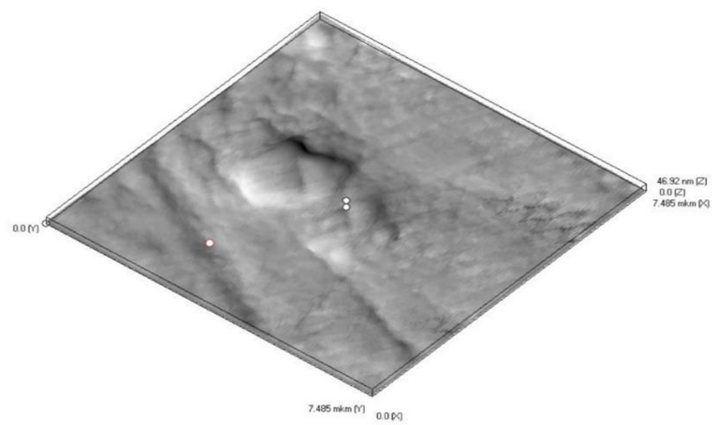


Fig. 4. Sample surface before (a) and after (b) ultrasonic treatment

Image analysis revealed the absence of abrasive grains on the surface after processing. Measurement of roughness and sub-roughness showed that despite an increase in Rz by 10 ... 12%, the maximum height of sub-microroughness decreased by 3 times. Oil absorption was chosen as a criterion for assessing the actual surface area. After processing, its value increased by 1.5 times (fig. 5).

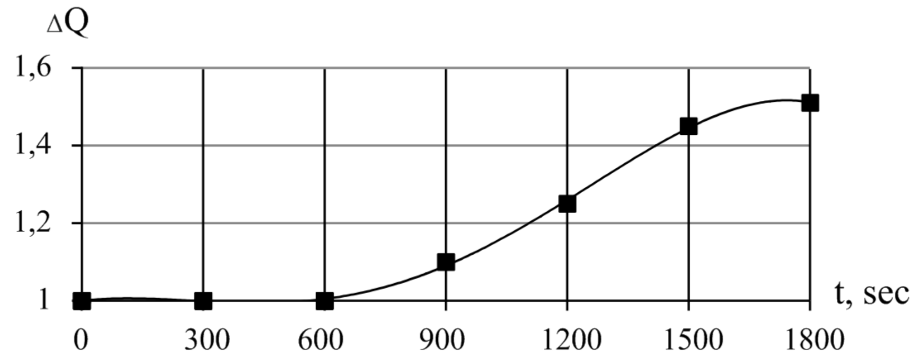


Fig. 5. Changes in the oil absorption of the surface after ultrasonic treatment

To assess adhesion, a single-layer paint-and-lacquer coating was applied to the prepared surface. Compared with the control sample, the breakout force increased from 3 to 5 MPa, which is associated with the formation of a large number of micro-cavities that increase the seizure area.

Conclusions

For various methods of obtaining coatings, one of the main stages of technology is the preparation of the surface for the application of the coating material. Preparation includes cleaning, degreasing, removing oxides and creating the required microrelief. The use of ultrasonic technology makes it possible to carry out the listed operations simultaneously. The impact of the effects created by ultrasound in liquid media promotes the separation of contaminants from the surface and their removal from the treatment area.

In addition, with a sufficient intensity of ultrasonic vibrations, the micro- and submicro-relief changes, which has a positive effect on the adhesion properties of the surface. Oil absorption of the surface increases up to 1.5 times, which leads to an increase in the force of separation of the coating from the surface.

This research was funded by the Russian Science Foundation, grant number No. 21-19-00660.

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