The oxide film formation under vibration processing in the high-resource parts manufacture in transport engineering

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Abstract. The results of pilot studies of the possible vibration shock and wave technology processes use when receiving an oxidic covering in aluminum alloys items are presented in the article. The technology of an oxidic covering forming in the course of the vibration shock and wave technology influence reflecting an entity of the process mechanical and chemical components complex impact on forming a surface covering layer is fulfilled. The mechanism of structural and phase impacts on a resource and quality of coverings that allowed to determine consistent patterns of receiving qualitative layers of a vibration chemical and mechanical oxidic coating on micro / a Nano level is installed, the causing obtaining the earlier unattainable quality and operational properties of a surface of the details made of aluminum alloys. The morphology researches of a vibrational chemical-mechanical oxide coating surface at the Nano level showed that the time is 66 nanometers thickness a cell of 600 nanometers consisting of 10 growth layers, at the same time the profile shift on the working environment rotation course is set. This structure of a covering promotes an increase in corrosion resistance as there is no access of an aggressive environment to the base metal. The mechanism of structural and phase influences, influence of granulometric characteristics and a dynamic status of the polymeric working environments used as the mechanical activator of the drawing coverings’ chemical processes is studied. The technological chemical solutions adapted to working conditions when receiving the combined chemical and mechanical oxidic coverings with the lowered maintenance of a silico-fluoride of sodium and chromic anhydride are presented. As a result of the covering surface research with the scanning probe microscope use it is established that the oxidic covering surface is not homogeneous and includes the elements which are in solution and in aluminum alloy composition

Introduction

Vibration processing makes it possible to provide the energy resulting effect of the combined effects from the mechanical and chemical components of the coating formation process. Vibration processing provides a change in the physicochemical properties of the surface layer of the item, as well as its activation. If the vibration equipment versatility is given, it can be used not only for coating formation processes, but also for finishing, cleaning and hardening operations, which is relevant since it reduces the production costs [1-5].

The problem formulation

The basis of the oxide film formation mechanism study is the method for determining the location nature, size, depth and shape of the processing traces when working in the environment of polymer
working media (polyethylene balls) in the process of oxidation and without an oxidizing solution and to establish the film quality, the general appearance of the surface using the optical and electron microscopic research methods.

There is information about the surface layer formation in the process of vibration processing in the medium of metal working environments. These processes are accompanied by the surface layers’ plastic deformation of the metal under conditions of multiple dynamic contact of the particles of the working medium with the item [6-14].

When combining the method of vibration processing and oxidation, the polymer working medium interaction and the surface layer of the processed material is carried out through the layer of the formed oxide film and the solution located in the contact zone. According to the theory of chemical oxidation, the formation of an oxide film, its growth is the result of the metal interaction with a working solution, which is carried out through the film pores formed during the oxidation.

When applying the oxide coatings on aluminum surfaces, the choice of a working medium is determined, first of all, by its physicochemical properties [2,3].

**Methods and materials**

The working medium should not interact with the process fluid (oxidizing solution). Taking into consideration the fact, that finishing and oxidation is the final operation in the process, the working environment should be light, flexible, not to allow scratches and dents. Therefore, polymer working fluids ø 2-3 mm were used as the working medium (Figure 1). Non-metallic bodies ensure uniformity of the oxide coating over the entire surface of the workpiece, act as suppliers of the oxidizing solution to the reaction zone, as well as smoothing irregularities.

Table 1 shows some characteristics of polyethylene.

| Indicators                              | Polyethylene |
|-----------------------------------------|--------------|
| Specific gravity, $G/$cm$^3$            | 0.92-0.95    |
| Tensile strength:                       |              |
| tensile, kg/cm$^2$                       | 110-140      |
| under compression, kg/cm$^2$             | 860-990      |
| when bending, kg/cm$^2$                  | 115          |
| Brinell hardness, kg/mm$^2$              | 25           |
| Thermal conductivity at 20°, $\text{kal} \cdot 10^4$ cm$^{-1}$ sec$^{-1}$ C$^{-1}$ | 2.1          |
| Material temperature limit, °C          | -45…100      |
| Water absorption in 24 hours at 20° C, % | 0.01         |
| Resistance to acids and oxidizing agents (under normal conditions) | racks |

**Figure 1.** Polymer media
The vibrating polymer balls, in contact with the surface growing under the oxide film combined process chemical component action, loosens it, which facilitates the oxidizing chemical solution access to the metal surface. The solution reactivity is enhanced by the activation of its constituent components. The ongoing processes’ intensity is noted not only in the reaction zone, but also in the direct contact zone. Under the influence of normal and tangential forces, the oxide film’s surface layer changes due to the vibrational mechanical effect of the system.

**Research results**

The shear processes of elastoplastic deformation include the sliding mechanism, which manifests itself in the movement of the grain’s one part relative to another. Outwardly, the manifestation of this displacement is expressed by the slip bands formation on the metal surface [1-6].

The experimental studies were carried out on the vibration equipment of the model, which has a sealed working chamber with a volume of 10 liters. The experiments were carried out using the polymer balls with a diameter of 2 to 10 mm, oxidizing solution (Na$_2$SiF$_6$ 2.5…3.5 gr/l, CrO$_3$ - 3.3…3.5 gr/l) and the samples of aluminum alloys AD1, AD9 and alloy AMc 10x10 mm in size, 2 mm thick, pre-polished. The amplitude varied from 2.5 to 4 mm and the oscillation frequency from 16 to 35 Hz. Processing time is 5 to 60 min. Working media was loaded into the chamber in a volume of 1/3 of the volume of the working chamber, 5 liters of oxidizing solution and 10 pcs. samples.

Figure 2 shows the structure of the aluminum alloy AD1 before and after processing.

![Figure 2. The structure of aluminum alloy AD1 (x 220): a – source; b – after application under vibration processing](image)

The characteristic traces of the polished aluminum alloy surface treatment AD1 in plastic balls are visible in Figure 3.

![Figure 3. Traces on aluminum alloy AMc after vibration processing in the plastic balls environment. Magnification - X 200. a – initial polished sample; b – after 15 min of treatment; c – after 30 min of treatment](image)

The photographs analysis shows that when assessing the roughness that determines the operational properties of the product, there are a large number of randomly located processing traces — protrusions and depressions — on the test surface. They have a variety of shapes, depths and sizes. Shallow recesses and longitudinal multidirectional risks of various shapes and sizes are visible, which
is a consequence of direct and oblique impacts of the polymer working medium. The contours of the tracks are uneven, which indicates a variable nature of the polymer ball’s movement relative to the surface being treated.

When considering the photographs of the samples surface treated for 15 minutes, the treated surface layer heterogeneity is noted. The distinguished polished surface areas and the areas with traces of destruction. With a longer treatment (35 min), contact and overlapping of many single traces on the metal surface is observed. When considering the processed traces, it is seen that the individual polymer balls, when interacting with the treated surface, leave an intermittent trace on it, consisting of smaller traces due to the balls’ movement nature. With such a cross-sectional arrangement of the considered processing traces, a peculiar microrelief that affects the quality of the vibrating chemical-mechanical oxide coatings is formed.

Analyzing the results obtained, it can be noted that during the vibrational chemical-mechanical oxide coatings application on the coating surface, elongated traces are formed, resulting from the sliding of the ball relative to the treated surface, and traces of a mixed type, which are the result of both sliding and direct impact.

A large number of traces covering almost the entire surface of the sample indicates the occurrence of elastoplastic deformation processes at the micro / nanoscale and loosening of the surface layer of the natural oxide film. These phenomena are of great importance in the oxide film and surface microrelief formation, since direct contact of the ball occurs along the oxide film.

Numerous studies have established the presence of plastic material flow in a thin surface layer of the sample along the movement direction of an individual granule, therefore, with a direct impact of a polyethylene ball, the deformation is directed deep into the sample. Most traces are characteristic of ball impacts directed at an angle to the surface, which cause brittle destruction of the oxide and the displacement of individual particles. Such interaction with the surface makes it possible to loosen the oxide layer with the formation of fine particles, which accelerates chemical processes. A part of the particles seizes with their juvenile surfaces with oxide, sometimes falling into the pores and reducing their volume, partially carried away by an oxidizing solution, partially compacted by subsequent impacts of polyethylene balls. Consequently, as a result of the microwave exposure, the oxide film loosens and smoothers out during its growth.

In the contact zone, due to the sliding impacts of polyethylene balls, a certain shift of the growing coating is observed towards the rotation of the working medium (Figure 4).

![Figure 4. Morphology of vibrational chemical-mechanical oxide coating: T=20 min, Aₓ=2 mm, scale - 100 nm](image)

The vibrating chemical-mechanical oxide coating surface morphology studies revealed the growth stages and dimensionality of the oxide film obtained by applying an aluminum alloy of the brand to the polished surface AL9 under modes: oscillation amplitude Aₓ=2 mm and frequency f= 33 Hz, time 5, 10, 20 min [10]. The initial aluminum alloy surface is shown in Figure 5 (scale 10 and 1 μm). The
The study of the coating surface at the micro/nanoscale was carried out on a Zeiss SUPRA25 analytical field emission electron microscope. On the surface, longitudinal lines are visible after machining up to 1 μm thick.

**Figure 5.** The initial surface of the aluminum alloy AL 9. Scale: a – 10 μm; b – 2 μm

Fig. 6 a and b show that the traces after polishing the samples before coating do not overlap. The vibrational chemical-mechanical oxide coatings’ formation at the micro level occurs on the metal surface in such a way that the coating copies the relief of the original surface, as evidenced by the contrasting stripes. In Figure 6c, d (scale 200 nm), the oxide coating nucleus’ shape and dimensions are clearly visible. It is established that not all the cells have an oval shape, with sizes ranging from 10 to 50 nm.

**Figure 6.** Surface morphology of a vibrating chemical and mechanical oxide coating. Application time 5 min. Scale: a – 20 μm; b – 200 nm; c –200 nm; d –200 nm

The conducted studies allow to conclude that the polyethylene fluids use is advisable to use for the vibrational chemical-mechanical oxide coatings’ formation, which in protective ability is 1.5 times higher than the oxide film obtained in a standard way.
Summary
This coating technology allows to increase the item’s service life and its reliability to reduce the cost, as well as environmental friendliness of production by reducing the concentration of the oxidizing solution [15-28].

As a result of the studies, it was found that the optimal conditions for the formation of vibrational chemical-mechanical oxide coatings:
- the oscillation amplitude is 2.5 mm,
- the oscillation frequency is 16 ... 35 Hz,
- the processing time is 15 min,
- the working medium is plastic balls Ø2…2.5 mm allow to obtain a coating with a thickness of 5 μm with the absence of the coating hydrogenated surface layer.

A relationship between the state of the initial surface and the operational performance of the parts after applying a vibrating chemical-mechanical coating is established, which made it possible to adjust the technological regimes and the manufacturing process of manufacturing high-resource parts in transport engineering.

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