Physical processes in capillary-porous material and coating in HF plasma at decreased pressure

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Abstract. When implementing the high-energy ions into an open pore and their movement from the material surface deep into a capillary-porous object, the ions are capable to tear both the strong covalent bindings and the numerous weak intermolecular bindings in the structure of capillary-porous material. In this connection, a combination of processes on suppression of kinetic energy, recombination of ions, release of the new charged particles occurs, which results in modification of internal pores’ surface in the capillary-porous material.

1. The Introduction
It was determined from experiments that the plasma ions are accelerated in electric field in the positively charged layer up to energy of 70-100 eV, and they form a flux to a surface of composite material (consisting of capillary-porous material and adhesive coating) with ion current density of 0.3 – 0.9 A/m². As a result, after the plasma influence, the composite surface texture is clear-cut, which facilitates the increase of coating adherence to capillary-porous material while its applying after HF plasma treatment.

2. Materials, methods and equipment
In the work the capillary-porous material means a leather with a coating. This is a system consisting of collagen (main protein capillary-porous material) and adhesive (polyurethane).

Modifications of capillary-porous material was made with the experimental high-frequency lowered pressure plasma device of the capacitive discharge.

For evaluation of the results of modifying capillary-porous materials with low-temperature plasma was used the adhesion of the coating to the skin which was determined in accordance with GOST ISO 11644-2002 and the structure was studied using a scanning electron microscope EVO 50XVP Carl Zeiss production. As a result of the experiment is established an increase in adhesion of the coating to the skin relative to the unmodified sample, was found to be 4 times and significant morphological changes in the coating, formed on the skin and the skin itself (the coating actually flows into the pores of the skin, increasing the contact area)

3. Results
Electrons in high frequency (HF) plasma make the oscillating movements synchronously with the change of electric field polarity. A flat specimen of the capillary-porous material placed into plasma will divide it into two parts (Pic. 1), therefore, due to synchronism of oscillations, the electrons come to the specimen alternatively, one surface after another.

The ions flow is coming towards the surface within the whole HF field oscillation period under the influence of the negative charge of an object, and the electrons are coming from plasma within a semi-period of positive intensity of the field in the form of the current impulse which duration depends on conditions of charge. That is why, the potentials on opposite sides of a specimen increase and decrease in antiphase relative to each other.

The minimum value of potential on each side corresponds to the floating potential obtained by a specimen in the direct current plasma:

\[ \varphi_{1 \text{min}} = - \left( \ln \frac{m_i}{\gamma m_e} \right) \approx 6 \div 18 \text{ B}, \]  

(1)

where \( \gamma = \frac{2 \pi}{c^2} \); \( c=1,247 \) [287]; \( m_i \) – ion mass; \( m_e \) – electron mass.

The mean value of HF potential, as per the measurement results [1,2] amounts to \( \varphi_{1 \text{mean}} \approx 70 \text{ – 100 V} \), which corresponds to oscillation amplitude of potential difference on the opposite sides of specimen \( \Delta \varphi = \varphi_{1 \text{max}} - \varphi_{1 \text{min}} \approx 99 \text{ – 141 V} \).
The presence of potential difference means that the electric field is formed inside the specimen. The magnitude of its intensity can be evaluated analytically: 
\[ E_{\text{av.}} = \frac{\Delta \varphi}{d} \approx 2 \cdot 10^4 - 10^5 \text{ V/m}, \]
where \( d \) – thickness of specimen (in this article, thickness of specimen amounts to 2 – 5 mm) [3].

Due to their electrical properties, collagen (base protein of capillary-porous material) and adhesive coating (for example, polyurethane) belong to dipolar dielectrics, thus, the influence of electric field leads to their polarization resulting in, a fixed electric charge is formed on the internal surface of pores (Pic. 2).

The time of polymers polarization does not exceed \( 10^{-13} \) s which 5 orders of magnitude less both the time of change of HF electric field intensity \( \approx 1.18 \cdot 10^{-8} \) s in each point in space, and the intervals between the electronic current impulses onto the specimen surface. Therefore, it can be considered that polarization occurs synchronously with the change of polarity of the electric field intensity and the electronic current rate.

Due to collagen and adhesive coating polarization, the strongly heterogeneous electric field is formed inside the porous space. In the vicinity to nanopore’s surface, the intensity of electric field reaches \( 10^9 \) V/m and higher (Pic. 3). In connection with the small distances between the oppositely charged surfaces (10-100 nm), an emission of electrons and ions from the nanopore surface is getting possible, with their further acceleration in the internal electric field and the transfer to the opposite side.

The relative dielectric permittivity of adhesive-polyurethane \( (\varepsilon=9,5) \) is more than 3 higher the same parameter of skin \( (\varepsilon=3,0) \). Therefore, the density of fixed charge on the adhesive surface faced inside is higher than the one on its internal collagen surface. As a result, the processes of emission and further recombination of the charged particles (ions and electrons) on the adhesive surface are more intensive.
4. Conclusions

The surface of capillary-porous material is characterized by presence of the opened and closed pores. Ions from plasma can penetrate the material to a depth of several micrometers. As shown above, the argon ions energy can reach 100 eV, and the density of ion current to surface $0.3 - 0.9 \, \text{A/m}^2$. When the high-energy ions possessing the sufficient mass entering an open pore and their further movement from the surface depth-ward the capillary-porous material, these charged particles may break from several stable covalent links up to several hundreds and thousands of weak intermolecular in the structure of material. Thereat, the complex processes of kinetic energy suppression and ions recombination, release of the new charged particles and, therefore, modification of internal surface of pores take place.

References

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