The influence of the composition of the working fluid on the characteristics of high-voltage electric discharge in the "hydrocarbon liquid–Al powder" disperse system

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Abstract: *Physical modeling of processes in a layer of Al powder in kerosene and ethyl alcohol during high-voltage electrical discharges in the spark discharge mode was carried out. The regularities of the distribution of plasma formations in the volume of the discharge chamber were studied when using ethyl alcohol and kerosene as working substances with an increase in the number of discharges. It is shown that the use of kerosene as a working fluid leads to an increase in the intensity of the formation of discharges between particles. It has been established that ethyl alcohol as a working fluid makes it possible to relatively stabilize the discharge mode, as well as to increase the number of discharges before the appearance of visual signs of the presence of residual nanocarbon, as a result of which it is possible to achieve greater dispersion of the processed powders. The possibility of synthesis of submicron and ultradisperse particles during high-voltage electric discharge processing of aluminum powder in a hydrocarbon liquid (alcohol or kerosene) due to the electrothermal effect of the discharge plasma on the powder particles has been confirmed.*

KEYWORDS: *KEROSENE, ETHYL ALCOHOL, ELECTRIC DISCHARGE, SPARK DISCHARGE, NANOCARBON, ELECTRIC DISCHARGE DISPERSION, ALUMINUM, PLASMA, PLASMA TECHNOLOGIES.*

1. Introduction

Currently, high-strength, light composite materials, in particular, multi-component heteromodular powder alumino-matrix composites that combine components with a high Young's modulus and elements with significantly lower values of the modulus of elasticity are increasingly being used in the creation of a number of parts and assemblies in machine building, shipbuilding, aviation and rocket and space technology. By controlling the volumetric content of the components, it is possible to obtain composite materials with the required levels of the main physical, mechanical and functional properties.

Aluminum is one of the most promising metals in modern metallurgy, which provides a unique complex of basic physical, mechanical and operational properties. Having such properties as low density, high plasticity and corrosion resistance, quite high strength indicators, significant thermal and electrical conductivity and wear resistance in a wide temperature- power range of operation, aluminum is widely used in various branches of modern technology. In many cases, it successfully replaces other non-ferrous metals and is even used as a substitute of steel. The wide usage of aluminum and its alloys can also be explained by the possibility to adjust the properties of the matrix material by heat treatment, to subject it to almost all types of pressure treatment, to obtain composite materials (CM) based on aluminum both by foundry methods and by powder metallurgy methods.

The creation of new metal-matrix materials with higher physical and mechanical properties than those obtained by conventional metallurgical methods is possible by physical methods of dispersion and synthesis of solid phases. One of these methods is the high-energy preparation of powders with the help of high-voltage electric discharges (HVED) [1, 2]. Further consolidation of HVED-treated powders allows obtaining materials with increased mechanical and operational properties.

The main idea behind the use of HVED for the preparation of initial powder mixtures is that during the treatment of powders in a hydrocarbon liquid, their particles are dispersed and the simultaneous synthesis of nanocarbon of various allotropic modifications occurs. This creates conditions for the carbidization reactions of the processed powder, which leads to the creation of dispersion-strengthening fillers of different stoichiometry during processing [1–4].

During HVED treatment, powder particles are thermally affected by plasma formations of interparticle discharges, which causes the transfer of metal (ablation) from the surface of the particles into the working liquid with subsequent recrystallization, as well as the impact of compression-decompression waves that arise as a result of the rapid expansion of plasma formations [1–5].

The prospects of using HVED for powders treatment are associated with the possibility of obtaining ultra-dispersed micro- and nano-sized particles with an increased level of free energy and, as a result, with an enhanced ability to intensively interact with the environment, in particular, with nanocarbon particles that are formed as a result of the pyrolysis of hydrocarbon liquids by a plasma discharge channel [1].

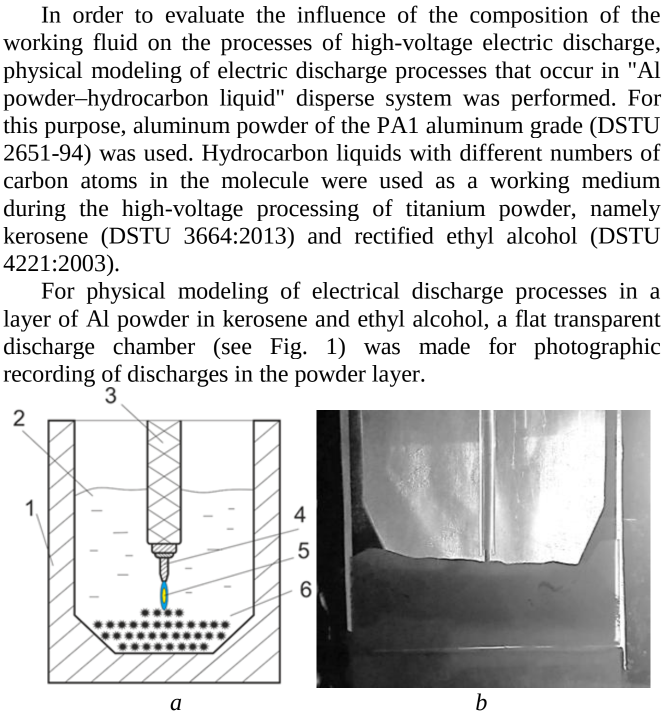
However, the processes of HVED treatment of metal powders in liquid dielectrics remain insufficiently studied, despite a number of known assumptions and hypotheses [1–5]. In particular, there are currently virtually no results of studies of the influence of the composition of the working environment on the patterns of development of high-voltage electric discharge. There are known works in which similar studies were performed for volumetric electrospark dispersion (electric discharge machining) [6–12], which makes it possible to use a similar methodology to study the HVED treatment of metal powders.

Therefore, the **goal of the work** is to study the distribution of plasma formations during the HVED in "Al powder – hydrocarbon liquid" disperse system.

2. Methodology

In order to evaluate the influence of the composition of the working fluid on the processes of high-voltage electric discharge, physical modeling of electric discharge processes that occur in "Al powder–hydrocarbon liquid" disperse system was performed. For this purpose, aluminum powder of the PA1 aluminum grade (DSTU 2651-94) was used. Hydrocarbon liquids with different numbers of carbon atoms in the molecule were used as a working medium during the high-voltage processing of titanium powder, namely kerosene (DSTU 3664:2013) and rectified ethyl alcohol (DSTU 4221:2003).

For physical modeling of electrical discharge processes in a layer of Al powder in kerosene and ethyl alcohol, a flat transparent discharge chamber (see Fig. 1) was made for photographic recording of discharges in the powder layer.



a *b*

Fig. 1. *General schematics of HVED process (a) and appearance of the processing chamber (b): 1 – processing chamber; 2 – hydrocarbon liquid; 3 – insulator; 4 – electrode; 5 – plasma channel; 6 – metal powder*

The use of a hydrocarbon liquid as a working medium for a high-voltage discharge makes it possible not only to grind treated powders particles, but also to synthesize various allotropic modifications of nanocarbon, which can form metal carbides due to its high chemical activity [2].

The distance between the transparent walls of the chamber was k = 5 mm. During processing, the "point-plane" electrode system was used, which allows to realize a spark plasma discharge in the powder layer. For photo-registration of plasma formations in the powder layer, a mobile camera was used, which recorded video at 1080p, 60 fps. The discharge chamber was connected to a capacitor bank with a capacity of C = 0.2 μF through an air spark gap switch that assured circuit commutation at the necessary operating voltage, and the charging voltage U was 20 kV.

3. Results and discussion

The analysis of the results of the study shows that at the beginning of the |HVED treatment in a hydrocarbon liquid (ethyl alcohol or kerosene) with a "point-plane" electrode system, plasma formations are concentrated mainly in the near-electrode zone (see Fig. 2, a, b) and are visually almost invisible.

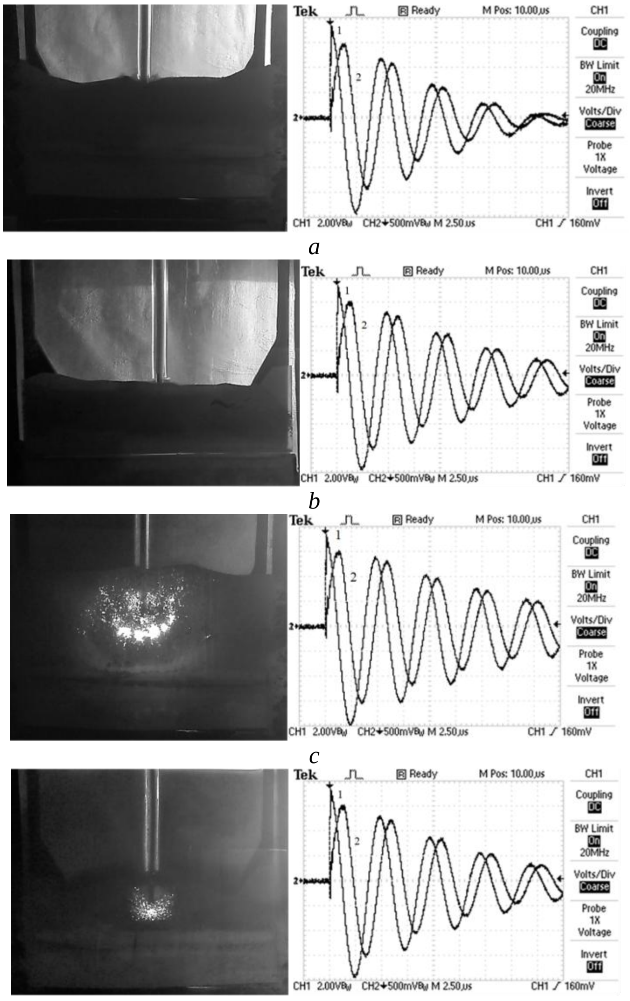


Fig. 2. *Integral photos and oscillograms of the first (a, b) and 50th discharges (c, d) during HVED treatment of Al powder in kerosene (a, c) and ethyl alcohol (b, d) with the "point-plane" electrode system: 1 - discharge voltage; 2 – discharge current*

It is worth noting the change in the location of the powder relative to the electrode system during treatment. After the first pulse the change in the configuration of the powder is almost not noticeable (see Fig. 3, 4), but then the cyclic appearance of plasma formations (and, as a result, vapor-gas cavities) in the near-electrode zone leads to the displacement of the powder from the central part of the chamber to its walls, which contributes to the strengthening of the hydrodynamic influence and the weakening of the ablation effects (see Fig. 5, 6).

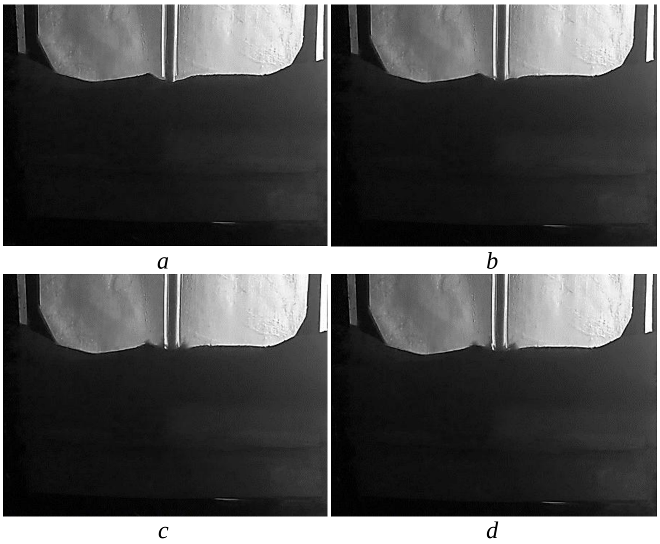


Fig. 3. *The dynamics of the first discharge in kerosene after 0 (a), 17 ms (b), 34 ms (c), 51 ms (d)*

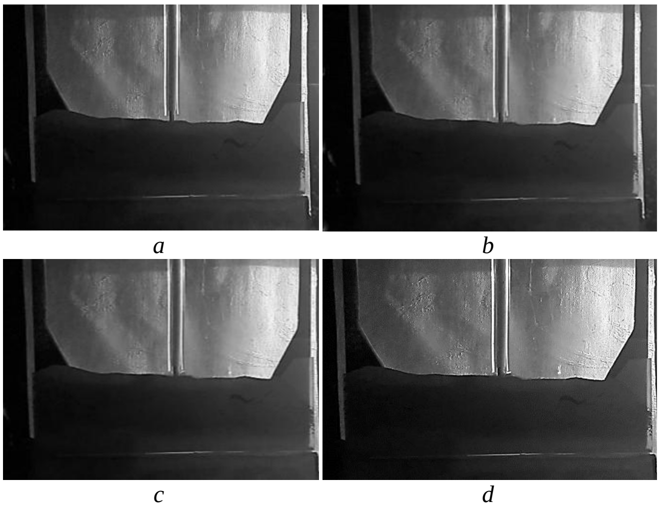


Fig. 4. *The dynamics of the first discharge in ethyl alcohol after 0 (a), 17 ms (b), 34 ms (c), 51 ms (d)*

According to the physical modelling of HVED treatment of Al powder in ethyl alcohol, the effect of nanocarbon synthesis is less noticeable, which correlates with the results, shown in [13], according to which, during HVED processing in the similar modes, the amount of synthesized nanocarbon using kerosene is ~ 5 times greater than the amount of nanocarbon synthesized in ethyl alcohol. This leads to less darkening of the working fluid after the same number of pulses (see Fig. 6).

During HVED treatment in ethanol, the pattern of distribution of plasma formations in the chamber volume remains practically unchanged as the number of discharges increases. In contrast to treatment using kerosene, where the intensity of formation of discharges between particles increases with an increase in the number of discharges, in ethyl alcohol plasma formations occupy approximately the same volume of the near-electrode zone regardless of the number of work cycles.

Thus, the use of ethyl alcohol as a working fluid for the HVED treatment of metal powders makes it possible to stabilize the discharge mode to a certain extent, as well as to increase the number of discharges before the appearance of residual nanocarbon, as a result of which it is possible to achieve greater dispersion of the processed powders. Instead, for faster and more effective carburization of the processed material, it is desirable to use kerosene as the working fluid.

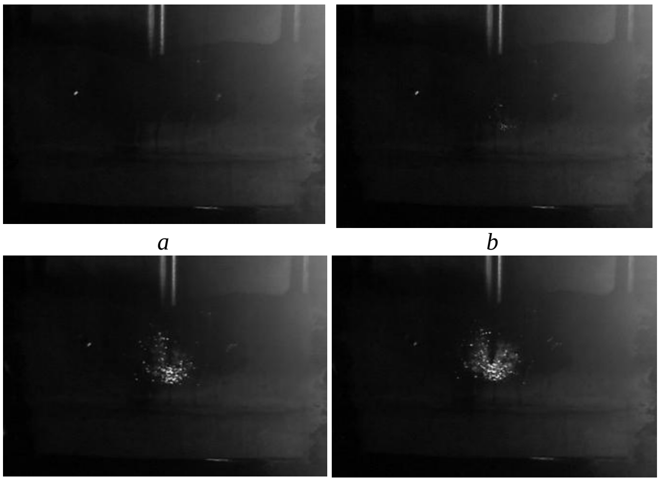

a *b*
c *d*

Fig. 5. *The dynamics of the 50th discharge in kerosene after 0 ms (a), 17 ms (b), 34 ms (c), 51 ms (d)*

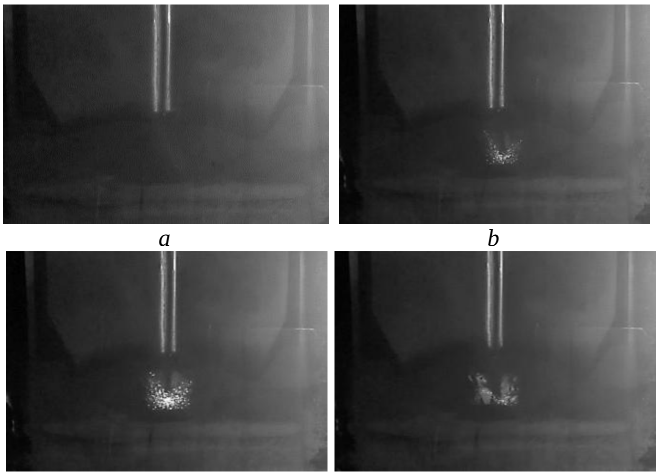

a *b*
c *d*

Fig. 6. *The dynamics of the 50th discharge in ethyl alcohol after 0 ms (a), 17 ms (b), 34 ms (c), 51 ms (d)*

4. Conclusions

1. It is shown that the use of kerosene as a working fluid leads to an increase in the intensity of the formation of discharges between particles with an increase in the number of discharges, and in ethyl alcohol plasma formations occupy approximately the same volume of the near-electrode zone regardless of the number of operating cycles.

2. Usage of the ethyl alcohol as a working fluid makes it possible to stabilize the discharge mode to a certain extent, as well as to increase the number of discharges before the appearance of residual nanocarbon, as a result of which it is possible to achieve greater dispersion of the processed powders.

3. Research has confirmed the possibility of synthesis of particles of the submicron and ultradisperse range by HVED treatment of aluminum powder in a hydrocarbon liquid (alcohol or kerosene) due to the electro-thermal effect of the discharge plasma on the particles of the powder.

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