Passivation process for superfine aluminum powders obtained by electrical explosion of wires

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Abstract

The process of passivation of superfine aluminum powders (SFAPs) ($a_s \leq 100$ nm), obtained with the electrical explosion of wires (EEW) method, has been studied. The passivation coatings of different nature (oxides, stearic acid and aluminum diboride) were covered on the particle surface. The process of passivation and analysis of passivated powders was studied by X-ray photoelectron spectroscopy (XPS), XRD, TEM, infrared spectroscopy (IR), mass spectrometry (MS), thermocouple method and bomb calorimetry. After the comprehensive testing of coatings, a model of stabilization of the superfine aluminum particles was suggested, explaining the anomalous high content of aluminum metal in the electroexplosive powders. The main characteristic of the model is a formation of charged structures, which prevent metal oxidation.

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1. Introduction

In the last decade, superfine powders of metals synthesized by several methods have become widely used in a number of different fields of material science [1]. Generally, the technological use of superfine aluminum powders (SFAPs) connects with their energetic formulations [2–4]. Superfine aluminum powders have a high combustion enthalpy, which is why they are widely used in propellants, explosives and pyrotechnics, as well as in SHS systems [5,6]. It is known that metals have a higher chemical reactivity in the high-dispersed state: this determines their field of application [7]. Chemical reactivity increases non-linearly with the decrease of particle size less than 1 μm, and especially <100 nm [8]. One manifestation of the high reactivity of superfine metal powders is their pyrophoric property. This property is characteristic for different superfine metal powders (Al, Fe, Ti, Zr, etc.) [9]. A paradoxical situation is observed for superfine aluminum powders (average size of particles $a_s \leq 100$ nm): storage of them in an inert gas is inexpedient because they are sintered spontaneously. As well as this, they are self-ignited under contact with
For the prevention of self-ignition, SFAP should be passivated. However, passivation is a problem because it reduces metal content (concentration): a high metal content is important for the material science exploitation of SFAP. One solution to this problem, focused-on in this work, is the application of protective films of various (chemical) nature on a particles’ surface.

Usual methods of SFAP synthesis under low-speed conditions (evaporation–condensation methods) allow one to obtain metal particles with a structure similar to that of bulk metal [10]. The formation of superfine metastable particles in pulsed electrical processes can be conducted under non-equilibrium conditions. One such method is that of electrical explosion of wires (EEW) [11]. The EEW method is characterized by a duration of process of between 1 and 10 µs, a plasma temperature \( \sim 10^6 \) K and an average rate of particle cooling of up to \( 10^9 \) K/s and a specific energy (entering a wire, \( e/e_s \)) of more than 1 MJ/kg [12]. Electroexplosive metal powders obtained by EEW have an energy-saturated structure and high metal content (discussed elsewhere [11]). The available data concerned with the process of stabilization of superfine metal particles is very poorly reviewed in the literary sources [13], which is in contrast to data on large particles [14]. In fact, in many works the self-sintered or strongly oxidized particles were only partially studied.

This paper reports a detailed study of the passivation of electroexplosive aluminum powders by air, including the dynamics of oxidation, X-ray photoelectron spectroscopy (XPS) and infrared spectroscopy (IR) studies of particle surface and mass spectrometry (MS) analysis of gases liberated from partially passivated SFAP. The processes of passivation directly in EEW, SFAP passivation by stearic acid and passivation by air are discussed. A mechanism of SFAP passivation by air is also proposed.

2. Experimental

In this work samples of SFAP produced by the EEW method, in various gas media (Ar, H\(_2\), (Ar + 10 vol.% H\(_2\)) and (Ar + 10 vol.% N\(_2\))), were investigated. Parameters of the powders obtained are shown in Table 1.

2.1. Passivation by air

Just after obtaining (in the steel container of the machine for SFAP obtaining by EEW (UDP-4G) [12]), SFAP (m \( \sim 150 \) g) was placed into a hermetic box of constant temperature, which contained argon gas (air content <0.1 vol.% at pressure \( P = 1.1 \) atm). These conditions of air-passivation were selected in more than one hundred preliminary experiments [15,16]. The passivation process was controlled with a chromel-alumel thermocouple (\( d = 200 \) mm) under the quasiadiabatic condition. The thermocouple was placed into a volume of powder. During passivation and storage, the probes from preliminary mixed powder were taken and analyzed by different methods (see Section 3). At least three measurements were conducted at each stage of every experiment, the results of which were statistically processed.

2.2. Passivation by stearic acid

Besides gas passivation by air, the study of passivation of electroexplosive SFAP by liquid (stearic acid) was carried out. A 0.05–0.25 mass% solution of stearic acid in toluene was poured into SFAP (m \( \sim 150 \) g)
immediately after obtaining in Ar before a contact with air. The mixture was then stored for 6 h, following which the treated powder was separated from the solvent and dried under $T = 20 \, ^\circ C$ and vacuum $P = 0.7 \, \text{atm.}$ to a constant mass.

### 2.3. Passivation during EEW

Passivation directly in the process of explosion is of particular interest because it reduces the pyrophoric property of powders and the time required for passivation is less than the above mentioned methods. Additives of reactive gases (O$_2$ and N$_2$) to argon during EEW lead to the formation of passivating films on particles and to an increase in the dispersiveness of WEE products [17]. Aluminum nitride film forms on a surface of particles during the direct passivation in the EEW process by addition of nitrogen. But AlN is oxidized and hydrolyzed during storage in air [18]. Therefore, the protective film in this case is, again, aluminum oxide.

The protective coating consist of aluminum boride applied to aluminum particles in the process of electrical explosion [19] can also be used as an alternative to oxide and nitride protective films. The experimental details were reported in our previous paper [7]: boron-contained coating on binding was applied on the aluminum wire before the EEW. The composition of the coating film on the superfine particles was obtained, by Electron Probe Micro Analysis (EPMA) “EPMA-1400”, Shimadzu, Japan, to be approximately AlB$_2$.

### 2.4. Facilities and techniques for powders analyses

The SEM and XPS apparatus used in this study was a “JSM-820” (Jeol, Japan). The powders were placed onto glued foil and analyzed in the apparatus chamber (after preliminary gold layer application). The XRD diffractometer was a “MAX-B” (Rigaku, Japan) using Cu K$\alpha$ radiation (Ni-monochromated). The 2$\theta$ range 10–90° was used. IR was obtained using “IR 75” (Germany); the powders were pressed in KBr and analyzed under the standard technique. The TEM study of powders was carried using a “H-8100” (Hitachi, Japan). The powders were suspended in ethanol and dried in air before testing by TEM.

### 3. Results and discussion

The obtained superfine particles, which were charged during EEW, were divided in the electric filter inside the EEW machine before collection. The charge of a particle can be determined by thermo-emission and ionization under electric field conditions. The stabilization of charge structures contribute to: (1) a high rate of cooling of products and (2) the presence of electromagnetic fields at EEW [20]. Mixtures of fractions or separate fractions of

<table>
<thead>
<tr>
<th>Gas media by EEW</th>
<th>Voltage by EEW (U) (kV)</th>
<th>$el_e$ (a.u.)</th>
<th>$[\text{Al}^n]$ (mass%)</th>
<th>$S_{sp}$ (m$^2$/g)</th>
<th>$a_s$ (nm)</th>
<th>$[\text{Al}_x\text{O}_y]$ (mass%)</th>
<th>Calculated thickness of oxide layer, nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar $+$ 10 vol.% N$_2$</td>
<td>30</td>
<td>1.82</td>
<td>88.0 ± 1.4</td>
<td>10.8 ± 0.3</td>
<td>210</td>
<td>19.0</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>1.71</td>
<td>87.9 ± 0.3</td>
<td>9.9 ± 0.3</td>
<td>220</td>
<td>19.1</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>1.62</td>
<td>88.1 ± 1.1</td>
<td>9.9 ± 0.9</td>
<td>220</td>
<td>18.9</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>1.45</td>
<td>88.5 ± 0.9</td>
<td>9.3 ± 0.3</td>
<td>240</td>
<td>18.4</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>1.30</td>
<td>90.9 ± 0.8</td>
<td>8.8 ± 0.25</td>
<td>250</td>
<td>16.1</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.13</td>
<td>90.0 ± 0.6</td>
<td>6.7 ± 0.2</td>
<td>330</td>
<td>17.0</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>0.92</td>
<td>91.0 ± 0.7</td>
<td>7.7 ± 0.3</td>
<td>290</td>
<td>16.0</td>
<td>5.6</td>
</tr>
<tr>
<td>Ar $+$ 10 vol.% H$_2$</td>
<td>–</td>
<td>1.10–2.12</td>
<td>90.2–93.6</td>
<td>7.7–15.8</td>
<td>140–290</td>
<td>1.1–3.7</td>
<td>0.2–1.7</td>
</tr>
<tr>
<td>Ar</td>
<td>–</td>
<td>1.52–2.25</td>
<td>86.3–89.1</td>
<td>18.5–13.8</td>
<td>120–160</td>
<td>8.4–8.8</td>
<td>1.5–2.1</td>
</tr>
<tr>
<td>Micron sized industrial Al powder</td>
<td>–</td>
<td>98.5 ± 0.1</td>
<td>0.8 ± 0.02</td>
<td>10000</td>
<td>1.0</td>
<td>13.6</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ $[\text{Al}_x\text{O}_y]$ = 100% − $[\text{Al}^n]$ − [adsorbed gases].
aluminum particles coagulated and were collected in the steel container after EEW. Taking into account that the explosion process is conducted under the gas (Ar) pressure \( P = 2.5 \) atm. and SFAP has a very low apparent density \((\sim 0.1 \text{ g/cm}^3)\), we assume the presence of gaseous Ar coating, adsorbed on the particle surface. This gaseous coating, we believe, prevents inter-particle contact during the first few hours after production and prevents sintering.

SFAP particles remaining on the electrodes of the electric filter after EEW possess low electrical conductivity, non-characteristic of metals. The migration of SFAP particles onto the electrodes of the filter is due to the electrostatic charges they possess, which are formed directly during EEW. The reactivities of the three different fractions of SFAP (i.e. the fractions from the positive and negative electrodes, and that which bypasses the electrodes altogether) were obtained using bomb calorimetry (Table 2). Bomb calorimetry is one of the standard methods for obtaining chemical reactivity in such energetic materials as SFAP [21]. The fraction of powder which passed through the electrodes of the electric filter showed the highest dispersion \( (S_{sp} = 9.0 \text{ m}^2/\text{g}) \), but an enthalpy of \( \text{Al}_2\text{O}_3 \) formation smallest amongst the three fractions (and lower than standard—see Table 2). SFAP collected from the negatively-charged electrodes possessed the lowest dispersion \( (S_{sp} = 5.4 \text{ m}^2/\text{g}) \), while having a value of \( \Delta H_{f}^{298} \) \( (\text{Al}_2\text{O}_3) \) higher than standard, the difference being \( \sim 137 \text{ kJ/mole} \), i.e. this fraction had higher metal content, but also a lower value of \( \alpha_s \).

Fig. 1 presents the data of the dependence of the temperature of SFAP (with \( e/e_s = 1.30 \) (Table 1)) on the passivation period. Initially (after SFAP production) the argon gaseous coating is retained on particle surface due to dispersion forces. According to thermocouple measurements, desorption of argon is accompanied by an endothermic process, which results in a decrease in sample temperature during the first 1–1.5 h (Fig. 1). Argon is gradually replaced by atmospheric components \((\text{O}_2, \text{N}_2, \text{CO}_2, \text{H}_2\text{O})\), which adsorb on the surface at first, but then react chemically with the aluminum particles resulting in the formation of oxide film. This process is signatured by the increase in the temperature in the curve of Fig. 1.

The results of MS analysis of the gases liberated from SFAP after the preliminary stage of passivation by air are presented in Table 3. The gases liberated from the electrically charged samples during heating are, most prevalently, components of air \((\text{N}_2, \text{H}_2\text{O}, \text{CO}_2)\) and \( \text{CO} \). A gas with \( m/z = 17 \) is liberated at \( 770 \) °C in the spectra of thermal desorption, with a peak intensity exceeding that of water \( (m/z = 18) \). If we assume that the ratio of peak intensities for \( \text{H}_2\text{O} \) and \( \text{OH}^- (m/z = 17) \) is 3, then this observation must be connected with the appearance of a new gas phase in the desorbed gas, possibly, that of \( \text{NH}_3 \) (see Table 3). Hydrogen begins to liberate at \( 200 \) °C in significant quantities and the liberation is most intensive at \( 600 \) °C (this data is not included in Table 3). A presence of hydrogen in the composition of desorbed gases is probably connected with accumulation of hydrogen during aluminum oxidation by water vapors during passivation. A sharp increase in the rate of hydrogen liberation is observed above \( 200 \) °C, which can be connected to the decomposition of hydrides, as well as the occurrence of desorption. The formation of ammonia is possible due to the hydrolysis of \( \text{AlN} \) formed in the reaction of SFAP...
with nitrogen (of air) during passivation. Catalytic reaction between N\textsubscript{2} and H\textsubscript{2} on the Al or Al\textsubscript{2}O\textsubscript{3} surface is another possible mechanism for NH\textsubscript{3} formation during passivation. Thus, oxide and hydroxide films, which have a considerable amount of adsorbed atmospheric gases, are formed on the particle surface during passivation and storage.

The measurements on \( S\text{\textsubscript{sp}} \) of SFAP with \( e/e_s = 1.82 \) (Table 1) during the passivation process (Fig. 2) showed that \( S\text{\textsubscript{sp}} \) rapidly increases at the initial stage of passivation, showing a maximum (with a value \( \sim 30\text{–}40\% \) grater than the initial value) at \( \tau \approx 2\text{ h} \), and then slowly decreases, approaching a value \( \sim 20\text{–}30\% \) lower than the highest value. Probably, during the first hours of passivation, the increase in \( S\text{\textsubscript{sp}} \) is connected to the formation of oxide–hydroxide film of a porous structure on the particle surface. Then, \( S\text{\textsubscript{sp}} \) slowly decreases because of crystallization and densification of the oxide film.

The passivation process of SFAP with \( e/e_s = 2.25 \) (Table 1), obtained in Ar and passivated by air, as observed by X-ray photoelectronic spectroscopy is shown in Table 4. The ratio of atomic concentrations [Al]/[O] varies from 0.86/1 for partially passivated SFAP ([Al]/[O] = 0.66/1 for Al\textsubscript{2}O\textsubscript{3}) to 0.42/1 for completely passivated SFAP. The oxygen content on the surface increases during passivation and the value of the [Al]/[O] ratio reaches 0.44/1 for stabilized SFAP. According to the electron paramagnetic resonance (EPR) data, a singleton signal (\( g = 2.0 \)) in the spectrum of SFAP is observed. In the IR data (Fig. 3) the absorption bands with the maximum energy values

<table>
<thead>
<tr>
<th>SFAP</th>
<th>Temperature of the beginning of gas liberation (°C)</th>
<th>Temperature of the maximal rate of gas liberation (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( m/z = 28 ) (CO, N\textsubscript{2})</td>
<td>( m/z = 44 ) (CO\textsubscript{2})</td>
</tr>
<tr>
<td>SFAP collected from positively charged electrode</td>
<td>240, 460</td>
<td>460</td>
</tr>
<tr>
<td>SFAP collected from negatively-charged electrode</td>
<td>240, 450, 550</td>
<td>550</td>
</tr>
<tr>
<td>Neutral fraction</td>
<td>20</td>
<td>230, 600</td>
</tr>
</tbody>
</table>
of 950 and 1440 cm\(^{-1}\) correspond to chemical-absorbed molecules of oxygen. A semi-empirical calculation, using of EPR and IR data, allows one to conclude that the molecules of oxygen connect to the surface of the particles by single Al–O–O bonds.

In non-passivated SFAP, obtained in the (Ar + 10 vol.% H\(_2\)) medium with \(e/e_s\) between 1.10 and 2.12 (Table 1), the content of metallic aluminum was 91–99.5 mass%. The content of metallic (non-oxidized) aluminum is determined by the standard volumetric method under the volume of liberated hydrogen during interaction of aluminum powder with aqueous (5 mass% NaOH) solution. During the passivation by air, the metal content exponentially decreased in a period of 6 days, and the quantity of aluminum stabilized at a level between 90.2 and 93.6% (see Table 1).

Completely passivated superfine particles obtained in Ar-based gas media had a shape close to spherical, and a smooth surface of oxide (Fig. 4). The calculated thickness of the oxide layer (1.5–2.1 nm, Table 1) agreed with the experimental one (1.8 nm, Fig. 4). It should be noted that the characteristics of passivated powders are strongly dependent on the production conditions employed. These characteristics are given in Table 1. The samples of SFAP were obtained using different values of \(e/e_s\). The area of specific surface increases for SFAP with increasing \(e/e_s\), but the content of metal is reduced in the passivated powders. The calculated content of oxides is high for this series of powders (more than 16 mass%).

With a decrease of the initial concentration of stearic acid in the solution, the content of metallic aluminum in SFAP decreases up to \([\text{Al}]^* = 86\) mass%.

Table 4
Effect of the duration of the passivation (storage) period in air on the atomic ratio [Al]/[O] in the surface layer for electric explosive SFAP (by XPS analysis)

<table>
<thead>
<tr>
<th>Al sample</th>
<th>Binding energy (eV)</th>
<th>Passivation (storage) period (h)</th>
<th>Atomic ratio [Al]/[O]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C 1s</td>
<td>O 1s</td>
<td>Al 2p</td>
</tr>
<tr>
<td>SFAP</td>
<td>284.8</td>
<td>531.7</td>
<td>74.3</td>
</tr>
<tr>
<td>SFAP</td>
<td>284.8</td>
<td>531.8</td>
<td>74.3</td>
</tr>
<tr>
<td>SFAP</td>
<td>284.8</td>
<td>531.6</td>
<td>74.2</td>
</tr>
<tr>
<td>SFAP</td>
<td>284.8</td>
<td>531.9</td>
<td>72.7</td>
</tr>
<tr>
<td>SFAP</td>
<td>284.8</td>
<td>531.1</td>
<td>73.0</td>
</tr>
<tr>
<td>SFAP</td>
<td>284.8</td>
<td>530.9</td>
<td>72.2</td>
</tr>
<tr>
<td>Micron sized industrial Al powder</td>
<td>284.8</td>
<td>531.6</td>
<td>74.3</td>
</tr>
</tbody>
</table>
During SFAP passivation by the solution of stearic acid, the highest quantity of metallic aluminum remaining is more than 3 mass% higher than with the passivation by air method (the highest value for SFAP in Table 1). The process of stearic acid build up on SFAP particles (forming the protective films) is accompanied by liberation of gaseous hydrogen, which can be connected to the occurrence of chemical reactions between the stearic acid and the aluminum. Thus, the treatment of unoxidized SFAP by stearic acid solution allows one to obtain passivated (non-pyrophoric) powders with the highest metal content compared with powders prepared under the analogous EEW conditions or passivated by air. Aluminum SFAP
modified by stearic acid does not react with liquid water for temperature $T < 40 \, ^\circ C$.

The initial concentration of stearic acid (0.05 mass%) was selected because if we were to have taken a lower concentration, the powder self-heating would have been initiated. It should be noted that if we were to have used pure toluene without the addition of stearic acid, then SFAP self-heating in air (after the same treatment and drying processes) would have occurred.

The stabilization of SFAP due to the formation of oxide film formed in EEW leads to the loss of $\sim 3$–$5$ mass% of aluminum, and to the decrease of a powders’ enthalpy (see Table 1). The chemical composition of SFAP, passivated by aluminum boride film directly in EEW, is (78.0 mass% Al + 18.0 mass% AlB$_2$) and was developed for use in propellants. Thus, electric explosive SFAP, obtained with the passivating coatings during the explosion, is possible by use of chemically active gases or reagents. Unfortunately, passivation with protective films (with the exception of AlB$_2$), formed during the EEW process, leads to a considerable reduction of metal content in SFAP.

According to XRD data (Fig. 6), particles of electroexplosive SFAP contain the aluminum phase only. But according to XPS (Table 4), the content of oxygen in the surface layers of particles is high, i.e. oxide film is not visible in XRD. A tendency towards an increase in Al$_2$O$_3$ content and, at the same time, a decrease in oxide film thickness is observed with an increase in the dispersiveness of electroexplosive SFAP (see Table 1). The experimental results show that the thickness and composition of oxide–hydroxide film depends on the gas medium employed in the EEW process and on the passivation conditions also. The thickness of the oxide layers was calculated on the basis of the $S_{sp}$ values and the mass of oxide present (Table 1).

Particles of electroexplosive SFAP have oxide films of around a factor of 2 thinner than those of industrial powder. Thus, the minimum thickness of oxide–hydroxide protective film can be obtained by EEW conducted in the gas medium Ar + H$_2$ or in pure H$_2$. The use of nitrogen addition to argon results in powders containing smaller particles, but with a low content of metallic aluminum.

Three experimental facts lie in the basis of the model for superfine aluminum particle formation in the EEW process (stabilized in air). The first is that a division of particles by the electrodes in the electric filter in an Ar atmosphere occurs. The second is that three different values for the enthalpy of Al$_2$O$_3$ formation are associated with the three electrically divided SFAP fractions. Finally, a decrease of oxide...
layer thickness with the decreasing of particle diameter is observed. These three facts allow one to assume that the “model of very thin film formation” [22] describes well the formation of protective oxide (hydroxide) films on the particles of SFP metals. The characteristic property of this model is that of a limitation of the oxidation process by electrostatic charge structures associated with the particles. Under the terminology of colloidal chemistry, the system “superfine aluminum powder-gas” should be classified as aerogel by the dimensional criterion. The case of very thin films assumes that the oxidation process is limited by the electric charge of the electrical double layer (EDL), i.e. the diffusion of oxidizer to the surface of metal is controlled by the EDL charge. EDL formation, according to Stern, is connected to the formation of dense monolayers (Helmholtz layers) and diffusion layers (Gouy layers) of ions [23]. EDL is similar to a spherical capacitor with a specific capacitance. In contrast to chemically inert substances, the metals form oxide (hydroxide) films on their surfaces. The EDL structure on particles of metals will have special features due to chemical processes. Metals are reducers and therefore they are primordially charge positive by the loss of electrons. The electric current in the electrochemical reaction of metal oxidation by oxygen and water (Faraday current) creates an additional potential and considerable capacitance. This is in contrast to usual capacitance, and, as so has a name “pseudo-capacitance”. The total polarization capacitance of a boundary of “metal-gas” is given by

$$C_{POL} = C_{EDL} + C_{PC},$$

where $C_{EDL}$ is the capacitance of the electrical double layer, and $C_{PC}$ the capacitance of the pseudo-capacitance associated with the chemical reaction. Equilibrium between a particle and its environment is achieved by mutual compensation of the chemical redox potential ($\mu$) and the electric potential ($\Delta E$) generated by the chemical processes.

Non-passivated charged particles retain their dispersion medium (Ar) due to strong “induced-dipole/dipole” interaction (Fig. 7). The particles which have no electric charge interact with argon by a mechanism of dispersion interaction. The passage of electrons from a metal surface through an oxide layer to the oxidizer proceeds at the same time as the passage of the oxidizer (protons $H^+$) themselves through the interface (metal-oxide), and the positive charge associated with the core of a particle increases due to these electrical currents. Positively charged particles accumulate electrostatic potential, which is necessary for the termination of oxidation–reduction process. In the case of negatively-charged particles, the oxidation–reduction process will intensify before the complete compensation of negative charge is achieved; an additional quantity of metal will oxidize to reach the positive potential necessary for the stabilization. However, the metal content in these negatively-charged SFAP particles will be low. Thus, the nature of the potential barrier, which ensures the stability of
electroexplosive SFAP is connected with the electrostatics of the particles.

Passivation by: (1) non-polar substances; (2) directly in the EEW process or (3) passivation by stearic acid all allow one to prohibit oxidation reactions in the border “metal surface-oxidizer” and thus achieve high metal content.

4. Conclusion

The stability of electric explosive SFAP during their passivation and storage is determined by their productions conditions. Regimes of electrical explosion should be selected for the purpose of obtaining powders with the highest metal content (Table 1). The preferential gas media during EEW is Ar + H₂. An increase in $e/e_s$ (in the range of values studied) leads to a reduction in the metal content. For reactive powders obtained with high metal content, it is necessary to separate the SFAP fractions, which settle on the negative electrode of the electric filter (Table 2). An additional increase in the content of metal in SFAP is accessible by passivation with film-forming liquids, e.g. stearic acid (C₁₈H₃₅COOH). The selection of passivation method for SFP of metal depends on the desired field of application. On the basis of experimental data, a chemical mechanism of SFAP passivation by air is proposed. The fundamental idea of this mechanism is the formation of very thin films on particles, a process which is terminated, ultimately, by their resulting electrostatic potentials.

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