# IMPACT OF OXIDATION PROCESSES IN AN OXYGEN ION ENVIRONMENT ON THE PROPERTIES OF MOULDINGS FROM ALUMINUM POWDERS

Viktor SKACHKOV, Olga BEREZHNA, Vira ANISHCHENKO, Ruslan GNATYSHAK

*Zaporizhzhia National University, Zaporizhzhia, Ukraine, skavira@ukr.net, berolgar@ukr.net, 37vera19@gmail.com*

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**Abstract**

The conditions for mouldings experimental samples based on aluminum powders of various granulometric composition are presented. The optimal compositions of the charge for pressing, the technology were worked out and the specific pressing pressure was found out, which is 168 MPa. Specific density (2.27 - 2.29 g/cm$^3$), Brinell hardness (2.10 - 2.13 MPa) and electrical resistivity (314 - 501 μΩ·m) were determined experimentally. The effect on the properties of the obtained samples of oxidation processes in the gas phase with different contents of oxygen ions at elevated temperatures up to 520 K and specific pressure up to 12 MPa was investigated. The concentration of oxygen ions varied from 53 to 70 wt%. The distribution of volume oxidation and its effect on the distribution of properties over the volume of samples were established. The hardness of samples in the near-surface layers increased by 36%, in the centre of the sample by 32%. This distribution of hardness indicates an almost uniform oxidation state of the samples throughout the volume. The increase in the average values of the density of samples by 4%, hardness by 35-40% and electrical resistance by 15-21% was determined.

**Keywords:** Aluminum powders, powder pressing, electrical resistivity, oxygen ions, volume increase

## 1. INTRODUCTION

The powder metallurgy finds the widest use for different working conditions of parts and products. By powder metallurgy methods, they produce products with special properties: friction and anti-friction parts of tribology applications, structural nodes and elements, tool and electrotechnical materials; composites of special purpose. The structure of powder aluminum alloys depends on the chemical composition of the alloy and the characteristics of the powder, the technological conditions in pressing, sintering, additive processes and secondary processing operations. Secondary technological operations (forging, rolling and extrusion) are able to increase the density and other functional properties of powder materials, which may exceed the properties of traditional deformable aluminum alloys [1].

The functional properties of parts and nodes based on aluminum are improved by the oxidation method. Oxidation can be carried out by electrolytic methods, by microarc oxidation method [2-4].

Microarc oxidation of aluminum alloys can provide protective anodic spark coatings up to 400 microns thick. The formation of such coatings is possible in various electrolytes [5-7].

Surface hardening and chemical resistance increase are implemented by methods of electrolytic oxidation in an electrolyte made up of organic acids. The ematal process was used to seal the oxide coating.

Volume sintering with simultaneous hardening of powdered blanks provides additive technologies which are implemented on two options.

One option corresponds to the term selective laser sintering. This option implements layered laser sintering of mouldings walls in a thin aligned layer of powder. In the second option, unlike the first, powder material is fed directly to a specific place in which the energy is supplied, the process of forming a melt zone and moulding sintering are taking place [9-11].

Improving the structure and functional characteristics over the volume of mouldings based on aluminum powders is a crucial task, both scientific and practical.

## 2. THE PURPOSE OF THE WORK

To assess the possibility of volume oxidation in the oxygen ions media of mouldings based on aluminum powders in conditions of increased pressures and temperatures, to establish experimentally the degree of change in local and integral functional characteristics of mouldings.

## 3. MATERIALS AND RESEARCH METHODS

PA-0 aluminum powders and PAP aluminum powder were used as raw materials. The chemical composition of the components is presented in **Table 1**.

Pressing of mouldings based on aluminum powders is implemented in cylindrical press die in the conditions of bilateral pressing at 25 ºC and specific pressure of 168 MPa according to the classical technology of powder metallurgy. The composition of the charge for pressing is presented in **Table 1**. The duration of mouldings holding at maximum pressure was 5 minutes, the pressure of mouldings pressing out was 33 MPa.

**Table 1** Chemical and granulometric composition of aluminum powders

| **Name** | **Al** (wt%) | **Fe** (wt%) | **Si** (wt%) | **Cu** (wt%) | **Moisture** (%) | **Grain size composition** (μm) | **Content in the mouldings material** (%) |
|---|---|---|---|---|---|---|---|
| PA-0 | 98.88 | 0.50 | 0.40 | 0.02 | 0.20 | 200 - 250 | 93 |
| PAP | 98.99 | 0.35 | 0.40 | 0.05 | 0.25 | 1 - 30 | 7 |

The density of mouldings was determined by hydrostatic weighing and calculated by formula (1):

$$\rho = m_1 \times \rho_1 \, (m_1 - m_2) \qquad (1)$$

where: $m_1$ *and* $m_2$ - the mass of the samples defined in the air and submerged in liquid, respectively; $\rho_1$ - fluid density (g/cm$^3$).

The hardness was measured with Brinell test using the 4.0 mm diameter ball and the 1.05 kH effort application for 30 seconds.

Electrical resistivity was determined on the device P 480.

The compression strength was determined on cylindrical samples with a diameter of 20 mm and a height of 20 mm. The tests were carried out on a FP – 100 test machine.

The oxidation of the mouldings was carried out in the autoclave at a pressure of 6.5 MPa and a temperature of 510 K in the oxygen ions media. The oxidation time was 30 minutes. The cooling was carried out with the autoclave.

## 4. RESULTS

For the preparation of the charge, subsamples of 930 grams of aluminum powder (PA-0) and 70 grams of aluminum powder (PAP) were taken. The subsamples were mixed in a vibrating mixer for 30 minutes until the components were distributed homogeneously by volume. The mouldings were pressed in accordance with section 3.

The characteristics of the mouldings samples were determined by the methods outlined in section 3 and presented in **Table 2**.

**Table 2** Parameters of mouldings characteristics prior to the oxidation process

| Sample No. | Density (g/cm$^3$) | Hardness HB (MPa) | Compression strength (MPa) | Electrical resistivity (μΩ·m) |
|---|---|---|---|---|
| 1 | 2.293 | 2.223 | 37 | 314 |
| 2 | 2.271 | 2.192 | 39 | 326 |
| 3 | 2.275 | 2.137 | 41 | 367 |
| 4 | 2.267 | 2.133 | 43 | 385 |
| 5 | 2.264 | 2.108 | 44 | 501 |
| 6 | 2.270 | 2.189 | 42 | 478 |

**Table 2** tested data show that the average density of samples is 2.52 g/cm$^3$, the average hardness is 2.164 MPa, the average electrical resistivity is 395 μΩ·m and the average compression strength is 41 MPa.

The obtained samples were processed by autoclave oxidation in media containing different concentration of oxygen ions. The diffusion activity of oxygen ions in high pressure conditions up to 6.5 MPa ensured the process of mouldings oxidation over their volume. Characteristics of oxidized mouldings samples are presented in **Table 3**.

**Table 3** Characteristics of oxidized mouldings samples

| Sample No. | Oxygen ions (%) | Weight (g) | Weight increase (%) | Diameter(mm) | $\Delta D$ (%) | Height (mm) | $\Delta l$ (%) | HB (MPa) | Strength (MPa) | Electrical resistivity(μΩ·m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 53.2 | 14.97 | 4.2 | 20.2 | 1.0 | 20.8 | 1.5 | 3.01 | 78 | 361 |
| 2 | 53.2 | 15.73 | 4.5 | 20.3 | 1.5 | 22.0 | 1.8 | 3.01 | 79 | 366 |
| 3 | 56.9 | 16.21 | 4.7 | 20.3 | 1.5 | 22.4 | 2.1 | 2.87 | 74 | 445 |
| 4 | 56.9 | 16.21 | 4.8 | 20.4 | 2.0 | 23.0 | 2.2 | 2.93 | 76 | 446 |
| 5 | 70.1 | 16.14 | 4.5 | 20.3 | 1.5 | 22.7 | 1.3 | 2.84 | 73 | 562 |
| 6 | 70.1 | 15.60 | 3.8 | 20.1 | 0.5 | 21.9 | 0.8 | 3.03 | 79 | 550 |

The results of the studies presented in **Table 2** and **Table 3** showed that the hardness of the processed mouldings samples increased by an average of 40.7%, the electrical resistivity increased by 14.9%, and the compression strength increased by almost 2.09 times.

The average increase in weight was between 3.8 and 4.8%, the diameter ($\Delta D$) was increased by 0.5 to 2.0%, the length ($\Delta l$) was increased by 0.8 - 2.2%.

It is important to distribute the characteristics of the samples over their volume. The distribution by volume of Brinell hardness samples is presented as an example. To this end, the samples were cut in height into two equal parts after pressing and oxidation process. On upper, middle and lower surfaces of the sample at 0.25 radius (*R*) intervals, starting from the centre of the surfaces, the Brinell hardness HB was determined. The hardness distribution results are presented in **Table 4**. From the analysis of the obtained results, it follows that the samples after pressing have the hardness in the centre lower by 1.8 - 1.9% than near the outer surface. Samples after the oxidation process on the upper radius have a difference of up to 1.4%, on the lower radius - 0.99%, on the central radius - 0.72%. Height along in the centre of samples the difference between the top and the middle for samples after pressing is 1.4%, for oxidized samples is 0.16%.

**Table 4** Distribution of the hardness HB (MPa) of moulding samples by height and radius (*R*) before and after the oxidation process

| **Height** | **0.00 *R*** | | **0.25 *R*** | | **0.50 *R*** | | **0.75 *R*** | | **1.00 *R*** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pressing | Oxidation | Pressing | Oxidation | Pressing | Oxidation | Pressing | Oxidation | Pressing | Oxidation |
| Top | 2.18 | 3.018 | 2.19 | 3.039 | 2.201 | 3.040 | 2.20 | 3.049 | 2.22 | 3.052 |
| Middle | 2.15 | 3.020 | 2.16 | 3.022 | 2.181 | 3.027 | 2.18 | 3.033 | 2.19 | 3.042 |
| Bottom | 2.19 | 3.025 | 2.19 | 3.043 | 2.203 | 3.051 | 2.21 | 3.053 | 2.22 | 3.055 |

The difference in hardness in the outer radius between the top and the middle for samples after pressing was 1.3%, and for oxidized samples 0.33%. The calculations presented show that the diffusion processes of oxygen ions in autoclave oxidation conditions are well developed and provide a high homogeneity of properties over the volume of samples.

## 5. CONCLUSIONS

Volume oxidation of mouldings based on aluminum powders in conditions of increased pressure up to 6.5 MPa and temperature up to 510 K in the oxygen ions media allowed to increase the Brinell hardness by 40.7%, to raise the electrical resistivity by almost 15% and increase the compression strength by 2.09 times. It was established experimentally that the hardness of the samples after the volume oxidation process is almost evenly-distributed over the volume, the maximum difference in Brinell hardness values does not exceed 0.33%.

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