ANALYSIS OF THE TECHNOLOGICAL AND MORPHOLOGICAL PECULIARITIES OF BRONZED POWDERS PRODUCTION FROM THE SWARF WASTES

Ob'єктом дослідження є технологія практичного одержання металевих порошків із стружкових відходів алюмінієвої бронзи з подальшим їх використанням у якості пігментів для поліграфічних процесів. В ході дослідження було виявлено, що розширення поверхні стружкових частинок, багаточисельні дефекти у вигляді макро- і мікротріщин, розщеплень та пор, спеціфічний мікрорельєф є сприятливими передумовами для їх подрібнення. Експериментальні напрацювання тонкої структури показали, що в процесі подрібнення стружки за рахунок додаткової пластичної деформації щільність дислокацій і величина мікротріщини кристалічної решітки порошкових частинок збільшується. Застосування прокатного комбайні з набором вібросит дало можливість використовувати в подальшому тонке подрібнення стружкових відходів. Дослідження форми і стану поверхні на оптичному і растровому мікроскопах надали необхідну інформацію для пояснення процесів, які відбуваються при подрібненні стружки. Отриманий результат показав, що мікродослідження зони стружкоутворення в БрАЖ 9-4 дало можливість вивчити механізм текстурування структурних складових α-фази, епітектоїд в утворених стружці. Це дозволило прогнозувати характер змінення останніх при подрібненні. Аналіз характеру руйнування поверхні стружкових елементів алюмінієвої бронзи у процесах подрібнення дозволив підтвердити ускладнення морфологічних, структурних та фізико-хімічних закономірностей останніх знов утвореними частинками порошку. А також можливість отримання дисперсного металевого пігменту для використання в поліграфії. Формування структурних співвідношень, незважаючи на масштаби утворюваних металевих стружкових відходів легованих кольорових металів і сплавів, особливо в умовах розвитку в Україні новітніх ресурсозберігаючих технологій.

Ключові слова: бронзувальні порошки, стружкові відходи, прокатний комбайн, морфологічні ознаки, пластична деформація, тонка структура.

1. Introduction

Improving the quality of printing and packaging products necessitates the use of various technological processes at printing enterprises, as well as the use of metallized materials to achieve the most popular effect among customers of the metallic luster of printing products. This effect allows the printing of metallized inks and bronzing. Metallic pigments used in bronzing are powders obtained using various technologies [1–3]. Metal particles are relatively recently used in printing, but the result makes itself felt [4–6]. 

The deformation zones in the visible chip element, as well as in the region, ahead and accompanying the deformation, have a dark color. Microscopic studies [11] show that this is due to the high density of slip planes and, accordingly, dislocations. The process increases with increasing depth of cut. The zone of advanced strengthening is much greater than the depth of the hardened layer under the cutter 0.05–0.30 mm. 

The deformation degree of the structural components is not the same. Slip lines have a certain crystallographic orientation in different grains. Being in the initial state in the dispersion (10–30 mm) and disoriented to the zone of plastic deformation, the α phase is first drawn out in a plane normal to the direction of movement of the tool, and then returns in the direction of its movement. In this case, the surface layer acquires a fibrous structure.
The grain boundaries in the deformation zone partially or completely lose their shape (Fig. 1).

![Localization of plastic deformation](image)

Fig. 1. Localization of plastic deformation

The technology for grinding chips of colored waste is described in [11, 12].

### 3. Research results and discussion

Being subjected to the impact of rotating parts in the attritor [11, 12], the swarf particles are divided into smaller elements. In the initial state, they have a wedge-shaped shape, and, due to the spin contact and surface deformation, the tops and ribs are crushed in the shredders, and the sharp profiles change to more rounded, sharp corners to obtuse ones. As a result, particles of columnar forms with a cross section close to trapezoidal are obtained. Although the chips are plastically deformed, that is, the material is significantly strengthened, during dispersion, dents are formed on the surface of the particles – areas with weakened intersections are formed. On subsequent impacts in these zones, capable of further plastic deformation, the concentration of defects becomes extreme and brittle fracture occurs due to micro and micro cracks that arise. As a result, particles are formed mainly in the form of an irregular quadrangle.

Since the newly formed particles inherit all micro and macro chips, and, therefore, have lower strength, as a result of the applied stresses, they are destroyed faster. But besides defects, they have their own background in the process of multiple load, new ones arise.

The most likely place for the initiation of cracks is the surface layers at the boundary of the particle, collapsing, squeezing the body, that is, in the places of the greatest shear stresses. Moreover, this process is facilitated by the already existing surface defects in the form of dislocations and microinhomogeneities.

Microscopic studies have shown that, in most cases, not one, but many cracks occur in particles that propagate predominantly in a zigzag manner, as a result of which they acquire a fragmentation shape. It should be noted that the powder obtained in the vibration machine has a surface more developed and saturated microinhomogeneities compared to the attritor powder [11, 12].

The microstructure of powder particles inherits the structural features of cast metal and chips. However, the depth and extent of the plastically deformed layers are greater. The microhardness of the alpha phase in the surface layers of the particles is 281–303 N, in the central – 230–270 N. Compared with the chips, the microhardness of the structural components increases on average 1.1–1.14 times during grinding, and compared to the cast metal 1.4–1.6 times. There is no significant difference in the hardness of the particles of the powder obtained in the attritor and in the vibratory grinders [12, 13].

The study of the fine structure shows that in the process of chip grinding, due to additional deformation, the dislocation density and the magnitude of the micro curvatures of the crystal lattice of powder particles increase [14].

The morphology of the swarf particles at different stages of grinding aluminum bronze swarf is shown in Fig. 2.

![Particle morphology at different stages of grinding aluminum bronze swarf on a rolling mill](image)

Fig. 2. Particle morphology at different stages of grinding aluminum bronze swarf on a rolling mill: a–c – 3–4 min (×201); d–e – 5–6 min (×241); f–i – 10 min (×781)

After receiving the bronzing powder, a bronzing paste is made. The composition of the mixture for bronzing oil-resin varnish 1 liter and bronze powder 400–450 g. Bronze powder rubbed on a small amount of varnish. The mixture is diluted with the rest of the varnish to working viscosity. For the manufacture of a mixture of aluminum powder it takes 200–220 g per 1 liter of varnish.

For operation, the mixture is made in small portions, which should be immediately used, since during long-term storage there is a strong wetting of bronze particles that settle to the bottom of the vessel. In the future, when bronze particles are applied to the surface, the bronze will not float into the outer layer of the film and it will lose its luster and become dull.

### 4. Conclusions

The study shows that, due to the properties of the surface of the swarf particles in the form of numerous defects, the prospect of their further use as powders of certain fractions. The peculiarities of the rolling of swarf particles consist of the fact that: first, they form a tape of small strength, and second, it easily collapses in a conventional attritor [11, 12]. The frequency of such operations with the above sequences allows to obtain powders...
of very small fractions of 10–20 microns with minimal oxidation. Further research will focus on the production of smaller particles with a lower degree of oxidation and a large number of their optical properties, since this directly affects the economic leverage of printed products.

The studies conducted in this paper are devoted to the development of technology for producing powders of various fractions in the form of dispersed filler for brake linings for road and rail transport (particle size up to 1 mm). As well as bronzing powders for finishing printing products (fraction 50–70 microns) and ultrafine powders as metal pigments for the production of metallized dyes [12–14].

References
1. Ogura K. Technology for Powder Production and Evaluation of Powders // Journal of the Japan Society of Powder and Powder Metallurgy. 2006. Vol. 53, Issue 4. P. 340. doi: http://doi.org/10.2497/jjspm.53.340
2. Solid State Sintered 3-D Printing Component by Using Inkjet (Binder) Method / Frykholm R., Takeda Y., Andersson B.-G., Carlström R. // Journal of the Japan Society of Powder and Powder Metallurgy. 2016. Vol. 63, Issue 7. P. 421–426. doi: http://doi.org/10.2497/jjspm.63.421
3. Zhang Y., Ye H., Liu H. Preparation and characterization of blue color aluminum pigments Al/ SiO2/PB with double-layer structure // Powder Technology. 2012. Vol. 217. P. 614–618. doi: http://doi.org/10.1016/j.powtec.2011.11.035
4. Kitsomboonloha R., Bera T., Dutta J. Direct Synthesis of Anisotropic Metal Particles by Ink Jet Printing Technique // Advanced Materials Research. 2008. Vol. 55-57. P. 585–588. doi: http://doi.org/10.4028/www.scientific.net/ams.55-57.585
5. Kronberger R., Wienstroer V. 3-D printer FSS using printing filaments with enclosed metal particles // Progress in Electromagnetics Research Symposium-Fall (PIERS-FALL). Singapore, 2017. doi: http://doi.org/10.1109/piers-fall.2017.8293245
6. Ishida Y., Nakagawa G., Asano T. Inkjet Printing of Nickel Nanosized Particles for Metal-Induced Crystallization of Amorphous Silicon // Japanese Journal of Applied Physics. 2007. Vol. 46. Issue 9B. P. 6437–6443. doi: http://doi.org/10.1143/jjap.46.6437
7. Voloshin V. S. Prirodna otkhodoobrazovaniya. Mariupol: Renata, 2007. 666 p.
8. Babaei V., Hersch R. D. Color Reproduction of Metallic-Ink Images // Journal of Imaging Science and Technology 2016. Vol. 60, Issue 3. P. 305031–3050310. doi: http://doi.org/10.2352/j.imagingsci.technol.2016.60.3.030503
9. 3D printing of high-strength aluminum alloys / Martin J. H., Yahata B. D., Handley J. M., Mayer J. A., Schaedler T. A., Pollock T. M. // Nature. 2017. Issue 549. Issue 7672. P. 365–369. doi: http://doi.org/10.1038/nature23894
10. Recent advances in inkjet printing synthesis of functional metal oxides / Liu X., Tarn T.-J., Huang F., Fan J. // Particuology. 2015. Vol. 19. P. 1–15. doi: http://doi.org/10.1016/j.partic.2014.05.001
11. Perspektivy vykorystannia struzhky aliuminiievoi bronzy v polihrafichnykh protsesakh / Kryuchok P. O., Roik T. A., Morozov A. S., Savchenko K. Yi. // Tekhnolohiia i tekhnika dрукarstva. 2009. Issue 3. P. 81–89.
12. Morozov A. S., Savchenko E. I. Ispol'zovanie metallicheskikh pigmentov pri izgotovlenii etiketki i upakovki // Upakovka. 2008. Issue 2. P. 28–31.
13. Morozov A. S., Ivansenko M. V., Shakhovaia O. V. Obrobka metalizovanych koloidnykh system // Tekhnolohiia i tekhnika dрукarstva. 2013. Issue 2. P. 47–53.
14. Metalizovana farbova plivka: pat. No. 68391 UA. MPK: C09D 11/20 (2012.01) / Morozov A. S. No. u201110329; declareted: 23.08.2011; published: 26.03.2012. Bul. No. 6.

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