Technology of manufacturing powder from aluminium chips

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Abstract. The paper studies two technologies of manufacturing powder from aluminium chips of A7E brand. It presents the research results of physico-technological properties of the manufactured powders with different fractures. The dependencies of apparent density and tap density on the fraction size are identified. The influence of annealing on the compression rate is revealed. The most effective technology of manufacturing aluminium powder with high technological properties is identified. Aluminium powder, manufactured according to the proposed technology, is recommended for application in manufacturing constructional parts.

1. Introduction
There has recently been a constant growth in the share of non-ferrous metals in the total volume of metal consumption in different industry branches. This growth is mainly due to the aluminum use, the manufacture of which has been growing fast in recent decades. Aluminium powder metallurgy is one of the most perspective and fast developing metallurgy areas [1]. Its advantage is a less products’ pressing force, and a low sintering temperature. The prevalence of aluminium is caused by its high durability, electrical and heat conductivity, corrosive resistance. On a broad scale aluminium powders are used in metallurgy and chemical industries. However, powder materials have a limited application in machine parts manufacturing; mainly while manufacturing special purpose products with unique service properties from sintered aluminium powders and alloys. Such a situation is due to the lack of scientifically-based technologies for processing aluminium billets and its alloys. Two main methods of obtaining aluminium powder materials are 1) high-temperature deformation of alloyed powders and mechanically alloyed powder mixtures; and 2) cold pressing of mechanically alloyed powder mixtures and their further thermal processing [2, 3].

A huge amount of chip waste is got in aluminium products manufacturing by machining and pressure processing. For example, while manufacturing an aluminum pipe from a rod by “Conform” method, the waste amount is up to 50 kg of chips out of 1 ton of a rod.

Methods of chip waste briquetting by screw extrusion are known [1]. Modern methods of chips processing by remelting are unprofitable due to the low level of preparatory measures for preliminary redistribution, considerable waste of metal during melting (up to 20-25%), high energy intensity of remelting, and technological process discontinuity [4, 5]. The works [1, 6] show the possibilities of manufacturing powder of different granulometric compositions from chip waste. The use of “chip” powder or its fractions agglomerates allows not only reducing the raw materials costs, and improving technical and economic characteristics of machine-building industries, but also improving the final product properties [2].
When extracting aluminium from waste, up to 90-95% of the electric power, needed for production of the same amount of primary aluminium, is saved; there is also no need for mining and processing of the feedstock. Aluminium powder processing is carried out by mechanical dry grinding in the inert gas atmosphere in a ball mill [1]; by dispersing melted aluminium by the air and further disseminating of the obtained powder and its grinding in the gas environment, containing nitrogen and oxygen. The drawbacks of these methods are explosion hazard and high cost.

This paper researches the method of manufacturing aluminium powder from chips waste, obtained during a rod processing by “Conform” method; it also studies the rod’s technological properties and presents the technology development for manufacturing rods with high mechanical properties.

2. Research methods

One of the aluminium chip sources is Conform-process due to which a pipe from the aluminium rod of the brand А7Е (State Standard – GOST 4784-97) is got. The chemical composition is given in Table 1.

|        | Fe   | Si   | Ti   | Al  | Cu  | Mg  | Zn   | Ga   | Admixtures |
|--------|------|------|------|-----|-----|-----|------|------|-------------|
|        | Up to 0.2 | Up to | Up to | Min 99.7 | Up to | Up to | Up to | Up to | The rest, each 0.02 |
|        | 0.08 | 0.01 | 0.01 | 0.02 | 0.04 | 0.03 |

Before getting into the Conform machine workspace, the primary rod is refined of the oxide film; tungsten-carbide matrices of a larger diameter than of a billet are used. A high-speed jet of cleaning liquid is injected into the machine workspace; a powerful swirl around the billet is created. The liquid swirl causes the high speed billet rotation while its surface is cleaned against the tungsten-carbide matrices. The obtained chips almost consist of aluminium oxide and are of curly shape (Figure 1, a). The chip elements thickness is 0.2-1.5 mm, the width is 5-15 mm. Such chips were used for the research.

![a](image1.png)  ![b](image2.png)

Figure 1. Photo of the primary chips – a; chips after knife grinding – b.

Manufacturing powder from chips was performed in two modes.

According to the first mode, oil contamination of the chips was removed by hot washing in the trisodium phosphate solution in a ratio of 10:1 in a tank with constant stirring for 30 minutes at 80-90°C. After washing, drying was carried out in the DC-200 drying cabinet at 90-95°C for 30 minutes. Further the chips were crushed in a knife grinder to the size of 2-4 mm and dispersed in a vortex-type knife mill with condensing oil to prevent the fractions adhesion and to reduce the agglomerates formation intensity to the size of different fractions. During the dispersion the mechanical alloying of powder fractions with aluminium oxide $\text{Al}_2\text{O}_3$ occurs.

According to the first mode, annealing was performed in the synthesis gas environment (72% $\text{H}_2$, 21% $\text{CO}$, 5.5% $\text{CO}_2$, 1.5% $\text{H}_2\text{O}$) at 650°C for 30 minutes in order to relieve the internal stresses in different powder fractions and burn the oil. Before and after annealing the technological properties were identified.
According to the second mode, manufacturing powder from chips comprised the following operations: preliminary grinding in the knife grinder; dispersing in the vortex-type knife mill with condensing oil; annealing.

The physico-technological properties of the powder were determined: granulometric composition; fraction shape; apparent density; tap density; compression rate.

After the processing we obtained powder mix material of the following granulometric composition: the material with granules less than 0.2 mm comprised 38.13%; the material with granules of 0.2-0.9 mm comprised 40.50%; the material with granules of 0.9-1.6 mm comprised 31.37%.

The powder fractions shape with the size of less than 0.2 mm is spherically rounded with the occurrence of a fine fragmentation fraction. The fractions shape with the size of larger than 0.2-0.9 mm is also spherically rounded due to commenced fractions agglomeration.

The apparent density of the powder mix material is 1.02 g/cm$^3$. The compression rate was determined at 800 MPa pressure, the density was 2.68 g/cm$^3$.

Compacts with a diameter of 24 mm, a height of 22 mm, and a density of 2.51 g/cm$^3$ were obtained by double-sided pressing in a floating matrix on a PD-476 hydraulic press with 1600 kN force.

The direct extrusion was chosen as the main operation [7]. Before the direct extrusion the compacts heating was done in the synthesis-gas environment at 650 °C for 20 minutes. The direct extrusion of rods was performed on the screw press with a F – 1730 arcuate drive with 1000 kN force in the mold tool (Figure 2). During the extrusion a lubricant, i.e. a colloidal solution of graphite in oil, was used.

![Figure 2. Mold tool scheme for hot extrusion of aluminium rod: 1 – lower plate; 2 – insertion; 3 – frame; 4 – pressing; 5 – matrix; 6 – punch.](image)

3. Theory

For the malfunctions removal during powder pressing a complicated-form compact with a compensator was designed (Figure 3) [8, 9]. While calculating the size of the compact, its density 2.7 g/cm$^3$ was assumed. Accepting the losses for trimming ends 0.3, the volume and the mass of the compact were identified by the rod mass. The compact diameter was calculated, considering its thermal expansion during heating and the possibility of providing a gap for free loading into the matrix container. Knowing the compact diameter and volume, the height was calculated. Based on the experimental studies, the reduction ratio during the extrusion was $\lambda = 16.8$. The diameter of the calibrating matrix section was considered to be equal to the rod diameter. The height $h$ of the compensator was calculated by the formula:

$$h = h_m \frac{1}{\cos \alpha} \Delta U,$$

where $\Delta U = U_1 - U_2$ is the gradient of the layers shifting speeds over the section of the extruded compact which equals to 1.02 – 1.07;

$h_m, \alpha$ are the height and the angle of the entry cone matrix.
The entry cone matrix angle was assumed as being equal to 60°, the height $h_m$ was calculated by the geometric parameters of the deformation zone [10]. The spherical compensator radius was calculated by the formula:

$$R_c = \frac{h_c^2 + R_{np}^2}{2h_c}$$

(2)

where $R_{np}$ is the radius of the primary compact; $h_c$ is the height of the spherical compensator.

The compensator radius for providing the punch stability while manufacturing the compacts was assumed being equal to the sphere radius reduced by $b$, which according to the experiments, has to be no more than 2 mm [11].

![Figure 3. The compact for aluminium rod extrusion.](image)

The diameter of the matrix $D_m$ for pressing the compacts was identified considering the value of elastic aftereffect, and its height $H_m$ was calculated considering the height of the loading chamber and the entry into the matrix cavity of the upper and lower punches (Figure 4) [10, 11].

![Figure 4. Mold tool scheme for manufacturing the compact with a compensator: 1 – lower plate; 2 – column; 3 – stop; 4 – extractor; 5 – spring; 6 – matrix plate; 7 – bushing; 8 – matrix; 9 – punch; 10 – flange; 11 – upper plate.](image)

![Figure 5. Mold tool scheme for hot extruding of the aluminium rod: 1 – extruded rod; 2 – plate; 3 – insert; 4 – frame; 5 – billet; 6 – punch; 7 – matrix.](image)

The diameter of the calibrating hole of the matrix for extrusion $d_0$ was calculated considering the rod shrinkage during the cooling and the acceptable deviation for aluminium rods. The rod shrinkage was identified experimentally. The mold tool scheme for manufacturing the compact with a compensator is presented in Figure 4.
As a result of calculations, the direct extrusion of a compact in the mold tool with a compensator was used (Figure 5). The stamping cycle is semicontinuous. At the initial moment the punch 6 is in the extreme upper position. The pressing 1, heated to the deformation temperature, is loaded into the matrix cavity 8, and is extruded to 2/3 of the rod length by the punch 2. Then the upper plate of the mold tool with the punch 6 fixed on it is raised; the next compact is placed; the compact is pressed out and extruded so that the previous billet completely leaves the calibrating section of the matrix. The cycle is repeated. The control operations are visual inspection, checking the sizes and the weight.

The aluminium rod mechanical properties were studied by tension and compression tests.

4. Results and Discussions

The preliminary grinding in the knife grinder is a preparatory operation for obtaining finer fractions with the size 2-5 mm (Figure 1, b).

The dispersion in the vortex-type knife mill was performed with condensing oil to prevent fractions adhesion and from forming agglomerates due to the aluminium fractions adhesion. After dispersing we obtained the granules of small size up to 2 mm. Annealing contributes to the oil burning and inside stresses relief in the powder granules of various fractions.

According to the first manufacturing mode, three powder fractions were obtained: fractions less than 0.315 mm; fractions of 0.315-2.0 mm; fractions of 2-4 mm. The fractions of 2-4 mm in size were obtained immediately after grinding. According to the second mode, the powder of the following fractions was got: fractions less than 0.2 mm; fractions of 0.2-0.9 mm; fractions of 0.9-1.6 mm.

It is found out that with the growth of fraction size the apparent and tap density increase (Table 2). With the fraction size of 2-4 mm the apparent and tap density are low. With the fraction size of more than 2 mm their packing is done less intensively due to the flat irregular curved shape of large fractions and their adhesion.

| Mode | Fraction, mm | Apparent density, g/cm² | Tap density, g/cm² |
|------|--------------|--------------------------|--------------------|
| 1    | <0,315       | 0.89                     | 1.35               |
| 1    | 0.315-2      | 1.25                     | 1.42               |
| 1    | 2-4          | 0.52                     | 0.56               |
| 2    | <0,2         | 0.48                     | 0.7                |
| 2    | 0.2-0.9      | 1.24                     | 1.42               |
| 2    | 0.9-1.6      | 1.33                     | 1.49               |

The shape of powder fractions with the size less than 0.315 mm, manufactured in both modes, is spherically round with the presence of small fragmentation fractions (Figure 6).

![Figure 6. The shape of fractions with the size of less than 0.2 mm (mode 2) – a, with the size of less than 0.315 mm (mode 1) – b, x80.](image)
When grinding the powder fractions in a vortex type knife grinder, the average fraction size decreases to the critical value with their further agglomeration which is determined by the dispersion time. Figure 7 shows the agglomerated fractions.

![Figure 7](image_url)

*Figure 7.* The shape of the fractions with the size of 0.315-2 mm (Mode 1) -- a, with the size of 0.2-0.9 mm (Mode 2) -- b, x110.

The compression rate of the powder, obtained according to Mode 1, increases with the pressure growth (Figure 8, a). At the same time, the powder fraction less than 0.315 mm is compacted less intensively due to the hardening of the fractions with aluminium oxide and their increased contact area. The fractions of 2-4 mm are compacted more intensively. The density of the samples, manufactured from the fraction of 2-4 mm, is 2.66 g/cm³. Annealing leads to the hardening relief and to the increase in the powder compression rate of all fractions (Figure 8, b). At 800 MPa pressure the powder density of medium and large fractions is 2.68-2.69 g/cm³.

![Figure 8](image_url)

*Figure 8.* The density of the powder, manufactured by Mode 1: a – before annealing; b – after annealing; fractions: 1 – less than 0.315 mm, 2 – 0.315-2 mm, 3 – 2-4 mm.

Similar data on the compression rate are obtained for the powder manufactured by Mode 2 (Figure 9). However, for the powder fraction less than 0.2 mm the compression rate is low at all the compacting pressures and at 800 MPa pressure the density is 2.67 g/cm³. At high pressures the compression rate of the samples with the fraction size of 0.9-1.6 mm and 0.2-0.9 mm tends to the constant value of 2.68 g/cm³. The annealed powders are deformed more easily, thereby ensuring the compression rate increase.
Figure 9. The powder density of different fractions, manufactured by Mode 2: 1 – less than 0.2 mm; 2 – 0.2-0.9 mm; 3 – 0.9-1.6 mm.

At the visual inspection there were no malfunctions on the surface of the rods, manufactured in the mold tools, with the deformation rate of 0.94 (Figures 10 and 11). However, the end part of the sample had friability 7 mm long, at the initial part there was a tightening 15 mm long (Figure 10, a, b). These malfunctions affect the yield and decrease the product quality.

The rod, extruded from the pressing with a compensator, did not have such malfunctions (Figure 11). Its density is 2.7 g/cm³.

Figure 10. Malfunctions during rod extrusion:
   a – tightening; b – friability.

Figure 11. The rod extruded from the pressing with a compensator.

A fine-grained structure with aluminium oxide is obtained. The average grain diameter is 152 nm. After the deformation at the extrusion ratio of 16.8 the ultimate tensile strength was 146 MPa, the relative elongation was 10 %, the relative narrowing was 18 %, the hardness was 32 HB. The mechanical properties after the compression are as follows: ultimate tensile strength is 347 MPa, yield
strength is 192 MPa, axial relative deformation rate is 49%. The rods diameter is 8.0 mm, with a
tolerance of extruded single precision rods with a diameter of 8.0 mm-0.58 mm.

5. Conclusions
Two technologies were developed for manufacturing powder from aluminium chips of A7E brand. It
is found out that applying both technologies it is possible to manufacture the powder fraction less than
0.315 mm with low technological properties. The powder with the fraction more than 2 mm has a
satisfactory compaction, but it is prone to agglomeration. The powder fraction of 0.315-2 mm is
recommended as the feedstock for construction materials. The powder, manufactured by chips
grinding with further oil dispersion and annealing, has the best technological properties.

The technology of manufacturing aluminium rods from the powder, obtained while chips waste
processing, is developed. According to the obtained mechanical properties such a rod can be used as
the initial billet for further processing.

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