EQUATION OF PRESSING OF NICKEL POWDERS

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One of the most important problems of the theory and practice of pressing powders is the establishment of the relationship between the pressing pressure ($P$) and density of the pressed compacts ($\gamma$). An analysis of many investigations of the pressing of various porous materials shows that at present there is no universal equation of compaction, and the many proposed equations satisfactorily describe pressing in individual, particular cases at certain pressures of pressing some particular material. The applicability of one or another equation can be determined only after an analysis of experimental data, such as was done by Kunin and Yurchenko [1] for powders of iron, copper, cadmium, bismuth, tin, and zinc.

In this article we propose a similar analysis of the results of pressing various nickel powders with the use of certain known equations.

a. Polytropic equation [2,3]:

$$P\gamma^n = C \quad \text{or} \quad P \gamma^n = C,$$

where $h$ is the height of the compact, $n$ and $C$ are constants.

b. Equations proposed by Bal'shin [4]:

$$\log P = \log P_{\max} - L (\gamma - 1),$$

where $P_{\max}$ is the specific pressure at 100% density of the compact, $L$ is a constant, $\beta$ is the relative volume equal to $\gamma_{\max}/\gamma$ ($\gamma_{\max}$ is the maximum density of the material being pressed), or of the polytropic type:

$$P\gamma^n = \text{const}.$$  

(3)

c. Lipson's equation [5]:

$$\log P = \log P_{\max} - L \alpha,$$

where $L$, a constant, is the modulus of pressing.

d. Equation proposed by Kunin and Yurchenko [6]:

$$\gamma = \gamma_{\max} \frac{K_0 e^{-\alpha P}}{\alpha},$$

where $\alpha$ is the coefficient of loss of compressibility in the presence of an increasing pressure, $K_0$ is the initial coefficient of pressing, $\gamma_{\max}$ is the conditional maximum density.

The following powders were used in the experiments: 1) carbonyl with particle sizes to 10 $\mu$m; individual fractions of "enlarged" carbonyl powder obtained by the sintering method with an inert filler (MgO) at 900°C in hydrogen: 2) 125-140 and 3) 30-45 $\mu$m; 4) electrolytic unscreened powder with a grain-size distribution: up to 45 $\mu$m, 22%; 40-45, 14.5%; 56-63, 5%; 63-71, 26%; 71-80, 30%, and 80-100, 2.5%; 5) powder with spherical particles obtained by heating electrolytic powder with an inert filler in hydrogen to the melting point, its grain-size distribution being: up to 40 $\mu$m, 13.3%; 40-45, 6.3%; 45-56, 9.0%; 56-63, 1.3%; 63-71, 3.2%; 71-80, 25.2%; 80-100, 13.3%; 100-125, 13.0%; 125-140, 8.6%; and 140-160, 6.5%; individual fractions of such spherical powder: 6) 71-80 and 7) 100-125 $\mu$m.

Pressing was done on a PG-10 press in 11.3-mm-diameter molds. The height of packing the powders was 10 mm in all cases and the height of the compact was measured to within ±0.05 mm. At least three compacts were pressed at each pressure and the average values of their parameters were used in the calculations. Figures 1-4 show data on the dependence of certain parameters of compacts on pressure, which

Fig. 1. Logarithm of specific pressure vs relative volume of compacts. In Figs. 1-4 the numbers of the curves correspond to the numbers of the powders used.

Fig. 2. Logarithm of density of compacts vs specific pressure.

Fig. 3. Logarithm of specific pressure vs logarithm of relative volume of compacts.

The pressing of carbonyl powder obeys Lipson's equation best [4]. As we see from Fig. 1 (curve 1), a straight line described by the equation

\[ \lg P = 3.08 - 0.86 \beta \]  

is obtained for it in coordinates \( \log P - \beta \) in the entire range of investigated pressures. Hence follows that the conditional value of pressure \( P_{\text{max}} \) corresponding to 100% density of the compacts is equal to \( 1.2 \cdot 10^9 \text{ MN/m}^2 \) (12 tons/cm\(^2\)) for carbonyl powder. The experimental value of density of a compact of carbonyl powder at this pressure and ratio \( h/d = 0.3 \) was 8.2 g/cm\(^3\).

For the enlarged carbonyl powder (curves 2 and 3) linearity was observed only in a small range of pressure, 98-294 MN/m\(^2\). As we see from Fig. 2, a linear relation was not obtained in coordinates \( \log \gamma - P \) for a single powder, i.e., equation of type (5), which was proposed for higher pressures, is not applicable in our investigated range of values. Evidently the coefficient of loss of compressibility (a) entering this equation changes with a change of pressure.

In Figs. 3 and 4 the curves constructed in coordinates \( \log P - \log \gamma \) and \( \log P - \log \beta \) are identical; this is understandable since Eqs. (1) and (3) are easily transformed into one another. As we see from these figures, the polytropic type equation nicely describes pressing: of enlarged carbonyl powders 125-140 \( \mu \text{m} \) in the interval 49-490 MN/m\(^2\) and 40-45 \( \mu \text{m} \) in the interval 98-490/MN m\(^2\); of spherical powders 100-125 \( \mu \text{m} \) in the interval 49-490 MN/m\(^2\); and of unscreened and 71-80 \( \mu \text{m} \) powders in the interval 98-490 MN/m\(^2\). We can note that the polytropic exponents for these powders are close, and with a decrease of particle sizes the linear relations occurs at higher pressures.

As we see from these data, pressing of different nickel powders cannot be described by a single equation. We should also note that up to a pressure of 49 MN/m\(^2\) compaction of the powders is extremely insignificant— in all figures the segments of the curves between 29.4 and 49 MN/m\(^2\) markedly depart from the general shape of the curves. Therefore we will henceforth deal only with pressures of the order of 49-490 MN/m\(^2\).

We can make several other general conclusions. In relation to the pressure dependence of the properties of the compacts we can distinguish three groups: I) carbonyl powders; II) enlarged carbonyl powders; and III) spherical powders. For the last two groups we note that deviation from a linear relation occurs at lower pressures, the larger the powder.

We did not obtain a linear relation for the unscreened electrolytic powder in the coordinates of the investigated equations. This relation was close to linear only in a small portion (98-294 MN/m\(^2\)) in coordinates \( \log P - \beta \).

In all figures curves 5 and 6, which belong to spherical unscreened and spherical powders of the 71-80 \( \mu \text{m} \) fractions, merge, i.e., these powders are pressed similarly. This is explained by the fact that the "average" size of the particles of unscreened spherical powder is close to 71-80 \( \mu \text{m} \) (<71 \( \mu \text{m} \) is 40%, >80 \( \mu \text{m} \) is about 35%, and 71-80 \( \mu \text{m} \) is 25%).

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