Deformation Process of Metal Powders in an Open Volume

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The mechanism of deformation of metal powders in a volume open on one side (rolling, wedge-type pressing) differs significantly from the mechanism of deformation in a closed volume (die compaction, hydrostatic pressing, etc.), where the whole powder is subjected to compression from all sides. In the latter case, the deformation is inevitably accompanied by a more or less uniform densification of the whole powder volume. When an open powder volume is deformed, either there is no densification at all or only part of the volume is affected by it. The mechanism of deformation under such conditions is virtually unknown as yet. Experimental investigation of the powder deformation mechanism must be simpler for wedge-type pressing than for powder rolling, because in the latter case the powder is not only compressed by the rolls, but also displaced in the direction of rolling. For this reason, the process of wedge-type pressing with a horizontal ram arrangement was chosen for the first stage of investigation into the mechanism of deformation of metal powders with a free surface.

For this study, the apparatus shown in Fig. 1 was designed and constructed. The base-plate 1 of the apparatus carries the box 2, in which the rams 4 are moved by the special screw device 3. A powder is poured into the box and is then compressed by the rams. The compacting surface of the rams is cylindrical, with a radius of 100 mm. External friction conditions can be varied by using special exchangeable cover plates. The screw mechanism enables either only one ram to be moved, with the other remaining stationary, or both rams to be moved simultaneously.

For the investigation of the powder deformation mechanism, use was made of an x-ray radiography technique described earlier [1]. X-ray photography was performed both with and without lead particles (d = 1-2 mm, l = 0.5-0.8 mm) stacked within the test volume. Another technique employed was based on the fact that shear strains in a powder lead to a change in density in the region of slip surfaces, which is recorded in x-ray pictures. Aluminum powder was the main material chosen for investigation. Tests were carried out using both smooth lining plates of Class 3 surface finish and lining plates with aluminum powder bonded to their surface. The deformation process was studied both on loosely poured and tapped powders. To obtain a qualitative picture of shear, the box was filled with separate layers of iron and aluminum powders.

At a substantial distance between the rams (more than 1-1.5 D), the whole volume of the powder may be divided, according to the character of deformation, into three zones: two impeded-deformation zones

![Fig. 1. Diagram of experimental setup.](image-url)
adjoining the rams and a central shear zone. Figure 2 shows an x-ray photograph obtained during the compression of iron (dark layers) and aluminum (light layers) powders. The powder located in the impeded-deformation zones moves together with the rams. No relative displacement of particles in these zones is observed. The whole remaining volume constitutes the central zone, in which, as the rams approach each other, shear strains take place and the powder is forced out. The size of the impeded-deformation zones can be found, when the ram radius is known, from the slope of the slip planes and the central angle α determining the line of intersection of the lower limiting slip plane and the working surface of the ram.

During the compression of a powder by rams, deformation is due to shear of individual powder layers along slip planes inclined at a certain angle to the direction of travel of the rams. On these planes, the powder is in a limiting stressed state, which is described by the well-known equation relating normal and tangential stresses in the statics of loose powder materials [2]:

$$|\tau_p| = \sigma_p \tan \varphi + c,$$

(1)

where $\tau_p$ and $\sigma_p$ are the tangential and normal stresses on the planes, and $\rho$ and $c$ are the internal-friction and cohesion coefficients of the powder.

As can be seen from the x-ray pictures in Fig. 2, the layers are not compressed and, consequently, they undergo no densification. In the initial stage of deformation, slip planes are formed separating the impeded-deformation zones from the remaining volume. Subsequently, deformation proceeds through the formation of new slip planes in the central zone.

X-ray photographs of the deformed volume of powder incorporating stacked lead particles yielded quantitative data on the slope of the slip planes and on the size of the impeded-deformation zones. Experiments demonstrated that the slope of a slip plane is a function of the stressed state in the region under consideration and of the properties (cohesion and internal-friction coefficients) of the powder, while the central angle α, which determines the height of the impeded-deformation zones, is a function of the external-friction coefficient.

Shear strains in a loose powder in the as-poured condition lead to densification along slip planes through closer particle packing. A powder subjected to tapping prior to compression will become loose along the slip planes. This effect can be observed both visually, when the box walls are transparent, and in the form of dark lines in x-ray pictures.

Raising the powder fill level and applying a pressure of 0.15 kg/cm² to the free surface have no effect on the formation of loose bands and on the size of the impeded-deformation zones. However, decreasing the powder bed height below a certain level close to the height of the impeded-deformation zones reduces the central angle α.

Analysis of stresses in the powder makes it possible to determine the direction of slip planes as a function of the properties of the powder. Let us consider the stressed state at some point K on a slip line LM for a two-dimensional problem (Fig. 3). The system of coordinates is chosen so that the x axis is parallel to the direction of motion of rams. The loose powder on the slip line is in a state of limiting equilibrium, the relationship between the normal and tangential stresses being established by Eq. (1). From the direction of the central zone, the full stress $\sigma_p$, which may be resolved into the axial components $\sigma_x$ and $\sigma_y$, acts at the point K. Shear in the powder takes place along the slip line in an upward direction. Thus, from the direction of the impeded-deformation zone, a friction stress $P_{fr}$ and a normal pressure N act at the point K.