DENSIFICATION OF POROUS METAL DURING
VOLUME PLASTIC DEFORMATION
IN THE ABSENCE OF WORK-HARDENING

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The object of the experimental work described below was to separate the geometric from the physical factor in the resistance to deformation of a porous solid undergoing densification in a die. Clearly, the intensity of densification diminishes in the course of pressing both because the rigidity of the porous skeleton grows with increase in the density of the specimen (geometric factor) and because the material of the porous solid experiences strain strengthening (work-hardening) (physical factor). The role of the geometric factor can only be assessed by eliminating the influence of work-hardening, for example by performing recrystallization annealing. Such intermediate annealing will not affect the position of the compressibility curve because the compressibility of a ductile metallic solid does not depend on the degree of coherence of its elements. This hypothesis, first tentatively advanced in [1], was conclusively verified in the present work.

A comparison was made of the densification behavior during volume deformation of electrolytic nickel compacts sintered to the same porosity at two markedly different temperatures - 1050°C, 1 h and 650°C, 1 h (Fig. 1). The minimum sintering temperature, equal to the final recrystallization temperature of the metal, was chosen so as to ensure that both objects were in a similar structure condition (free from internal stress). The recrystallization temperature was determined by measuring the fall in hardness during the heating of a specimen deformed from 66 to 83% relative density and by ascertaining that all continuous interference lines in Debye photographs had vanished. Primary recrystallization came to an end after annealing for as little as 5 min at 650°C. Deformation was performed, using a 10-mm-diameter die, in an RM-102 tensile testing machine at loads of up to 2 tons and in a UMM-10 machine at loads exceeding 2 tons. Pressure measurements were accurate to 1%. The height-to-diameter ratio of the specimens was 1:1. Specimens intended for subsequent sintering at 1050°C were pressed with a 2 wt.% paraffin wax addition.

The curves shown in Fig. 1 virtually coincide, which is evidence in support of the hypothesis put forward in [1], stating that the compressibility of a porous solid is independent of its degree of coherence (quality of interparticle contacts). By alternating pressing at any given pressure with recrystallization annealing we can approach as closely as desired some equilibrium value of overall strain, which is determined by the pliancy of the porous skeleton as a geometric configuration and depends on the yield strength of the material of the skeleton in the unhardened condition and the starting porosity. By performing such densification with intermediate annealing operations to a constant volume at various values of compaction pressure it is possible to construct, using limiting values of porosity, a curve characterizing the densification of the porous structure of a given material as a geometric configuration. Such a curve can be called a geometric strengthening curve of a porous metal. In Fig. 1 are shown geometric strengthening curves for electrolytic nickel specimens initially sintered for 1 h at 1050°C and for 1 h at 650°C (in both cases the porosity after sintering was 53%) and, to obtain a basis for comparison, compressibility curves for similar specimens in the work-hardened condition. It was found that initial high-temperature sintering improved compressibility, which was apparently attributable to more effective refining of the material during the high-temperature annealing in hydrogen, resulting in a lowering of the yield point of the matrix metal in the unhardened state. As the curves were constructed under conditions of freedom from work-hardening, this “biographic” difference was preserved even at the highest values of density. When recrystallization annealing was not performed, the difference vanished at low values of applied pressure, and a single curve
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Fig. 1. Compressibility curves for electrolytic nickel specimens sintered for 1 h at 650°C and 1 h at 1050°C (1); after removal of work-hardening for specimens sintered for 1 h at 650°C (2) and 1 h at 1050°C (3); theoretical curves for nonwork-hardenable material, plotted with Green's (4) and Skorokhod's (5) formulas.

Fig. 2. Compressibility curves for electrolytic nickel specimens sintered for 1 h at 1050°C (1); for similar specimens after removal for work-hardening (3); for specimens sintered for 1 h at 1050°C with pore-forming agent (of < 63-μm particle size) (2); for similar specimens after removal of work-hardening (4).

was obtained representing the compressibility behavior of specimens sintered at the low (650°C) and high (1050°C) temperatures.

Compressibility curves for specimens with different types of porous structure are shown in Fig. 2. A comparison is made in this figure of the compressibility and geometric strengthening behavior of electrolytic nickel specimens of the same total porosity (50.5%) sintered for 1 h at 1050°C but produced by two different methods: 1) conventional pressing and sintering (specimens with "natural" porosity) and 2) pressing of a charge containing a pore-forming agent (ammonium bicarbonate powder of < 63-μm particle size) which evaporated during sintering (specimens with "artificial" porosity). In the latter case the pore size and shape were determined largely by the particle size and spatial distribution of the pore-forming agent. From Fig. 2 it can be seen that better compressibility was exhibited by the specimen with "artificial" porosity than by the "naturally" porous specimen. The difference remained even after the removal of work-hardening, and was thus linked with differences in the geometry of the porous structures.

The fact that a specimen with "artificial" porosity exhibits better deformability in the direction of initial pressing is apparently due to pore shape anisotropy after sintering. The reason for such anisotropy is that during pressing particles of the pore-forming agent or their flat agglomerates tend to orient themselves so that their wide cross sections are perpendicular to the acting stress. This is borne out by the data of Fig. 3, which shows a comparison of the compressibility, in the direction of initial pressing and at right angles to it, of electrolytic nickel specimens sintered for 1 h at 1000°C with 16% of ammonium bicarbonate (having a porosity of 56.7% after sintering) and a specimen of the same porosity produced by orthodox pressing and sintering under the same conditions. As can be seen, the specimens exhibited better compressibility in the direction of initial pressing than in a direction at right angles to it. The compressibility curve for the specimen with "natural" porosity lies between the compressibility curves of the specimens with "artificial" porosity deformed in the two directions at right angles to each other. Similar results concerning the anisotropy of the porous structure were obtained by measuring the velocity of propagation of ultrasonic vibrations. Thus, it has been demonstrated that the position of the geometric strengthening curve of a porous solid depends on