

THEORY AND TECHNOLOGY OF FORMING PROCESS

PRESSING OF LONG-LENGTH PELLETS FROM TITANIUM HYDRIDE POWDER

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The paper examines pressing of the titanium hydride powder in a die lubricated with adipose to produce pellets with $H/d \approx 4/1$ and additional compaction of these pellets with a combined lubricant separating them from the die. The pellet extrusion pressure in the additional compaction process is one order of magnitude lower than when the powder is pressed in a lubricated die. This is indicative of drastic decrease in the external contact friction during additional compaction. Compaction of the titanium hydride powder mixed with a water-soluble organic lubricant has been experimentally studied.

Keywords: long-length compacts, pressing, titanium hydride, porosity, additional compaction, lubricant.

INTRODUCTION

Two major process options are employed to produce pellets from metal powders: (i) make short pellets of complex shape to be turned into a finished product by sintering and (ii) make long-length cylindrical pellets of equal thickness by vertical pressing to obtain sintered parts of uniform density along the height.

The former process is supported by the known pressing technologies [1–5]. Nevertheless, the latter process also needs to be technologically supported. It is likely that dense sintered long-length metal powder compacts of equal thickness are not much in demand because their production is virtually impossible or extremely difficult. It can be assumed that a long-length compact has height-to-diameter ratio H/d equal to or higher than 16/1, being twice the 8/1 value that was reported in [4] to be limiting for compacts. The common techniques used to make long-length powder billets have some drawbacks along with undoubted advantages. The drawbacks are high porosity after removal of the plasticizer in extrusion forming [5], low strength at interfaces between different powder portions in dosed powder feeding and compaction in the matrix [6], uneven density distribution across the billet cross-section after pressing with a beveled punch [7], restrictions on the shape of billets in rolling [5], and short life of shells and restrictions on the size of process chambers in isostatic pressing [5]. Apparently, there is no simple or clear procedure to determine if long-length billets can be obtained without special dies.

The objective here is to study the potential for producing long-length compacts without using high dies and identify process features pertaining to pressing of shortened billets.

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EXPERIMENTAL PROCEDURE

The starting material was as-delivered titanium hydride TiH_2 powder (as per TU U 14-10-026-98), chosen with the further prospect of producing titanium parts [8–13]. The titanium hydride density was accepted to be equal to 3.9 g/cm^3 [10].

Long-length pellets were produced at $15\text{--}27^\circ\text{C}$. The potential for producing such parts was determined as follows. A one-piece cylindrical die with a working diameter of 10 mm and a height of 100 mm was first used for single-stage pressing. A TiH_2 powder sample weighing 11 g was loaded into the die. To reduce external contact friction, the die channel was evenly lubricated with adipose with a high molecular weight and a high content of stearic acid (pursuant to the procedure described in [14]) prior to loading each sample. The sample was subjected to single-stage (without additional compaction) double-action pressing; the lower punch was inserted into the die before the powder sample was loaded. After that, the one-piece die was placed on two rubber spacers 12 mm thick, located on a support steel plate. The samples were compacted at different pressures; the maximum force required to push the pellet out of the die was determined. The pellet maximum extrusion pressure was calculated as the quotient of the maximum extrusion pressure divided by the lateral surface area of the compact. The compacted pellets were weighed and their diameter and height were measured to calculate their density and, accordingly, porosity.

Two different dies were used for two-stage pressing of long-length pellets. The TiH_2 powder samples were first subjected to single-stage pressing at different pressures in an unlubricated split die with a working diameter of 10 mm and a height of 100 mm. The pellets were weighed and measured to calculate their density and porosity. Then the pellets were placed into a one-piece die 10.5 mm in diameter and 70 mm in height for additional double-action compaction. Prior to additional compaction, a combined lubricant layer 0.11–0.15 mm thick was applied to each pellet, which was then put into the die for single-stage additional compaction at 800 MPa.

The above experiments show that the pellets produced in the lubricated one-piece die can be additionally compacted using a combined lubricant.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 1a shows how the pellet porosity varies with compaction pressure in the lubricated one-piece die. In the pellet pressing process, the load first smoothly increased to 500–550 MPa and then increased unevenly; this might be because the outer lubricant layer lost its integrity and enhanced friction of titanium hydride against the die wall in such areas. The height-to-diameter ratios and the ratios of pellet extrusion pressure to pellet lateral surface area are shown in Fig. 1b. At 700 MPa, the pellets are ~40 mm in height; i.e., they are shorter than the die (100 mm). Along with the punch penetration depth, this difference can be accounted for in the design of full-size dies [5, 6].

Figure 2 shows how the porosity of initially pressed and additionally compacted pellets varies with the starting compaction pressure in the unlubricated split die. Unlike pressing in the lubricated one-piece die, the process was accompanied by extremely uneven load increase over the entire range of compaction pressures; this indicated that the unsteady pressing process was mainly due to high external contact friction of the TiH_2 particles

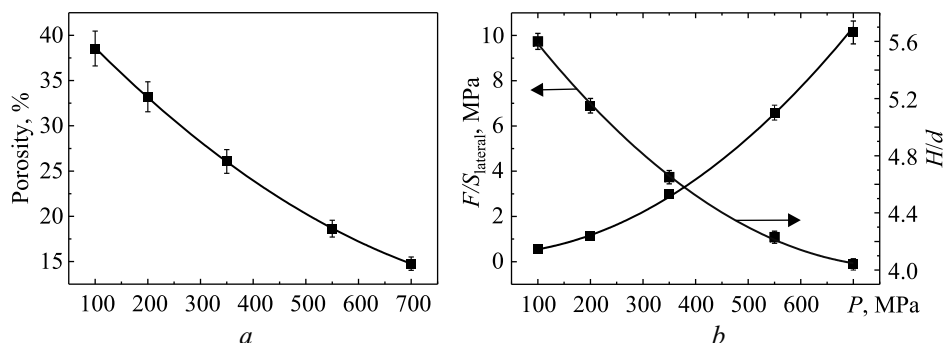


Fig. 1. Porosity of the TiH_2 powder pellets (a) and H/d and F/S_{lateral} ratios (b) versus compaction pressure in the lubricated one-piece die

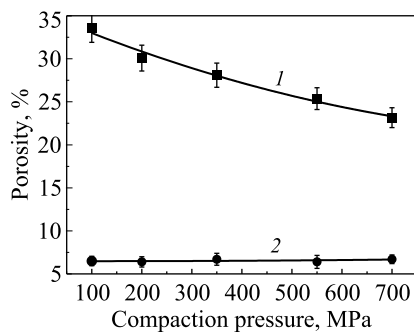


Fig. 2

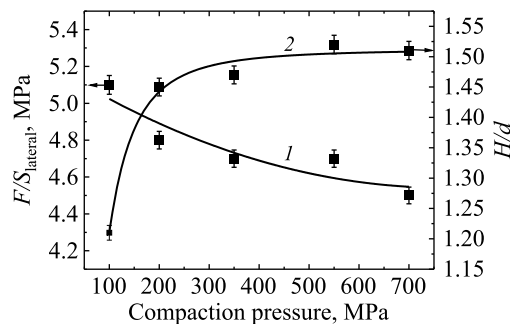


Fig. 3

Fig. 2. Porosity of the TiH_2 powder pellets versus compaction pressure in the unlubricated split die (1) and after additional compaction of the pellets (coated with a combined lubricant) in the one-piece die at 800 MPa (2)

Fig. 3. H/d (1) and $F/S_{lateral}$ (2) ratios in additional compaction of the TiH_2 powder pellets versus the starting compaction pressure in the unlubricated die

against the unlubricated die wall. Therefore, unlubricated die pressing of the TiH_2 powder was found to be technically unfeasible. Figure 2 illustrates that additional compaction of lubricated pellets decreases their porosity, making it very close to the initial porosity.

Figure 3 shows how the H/d and $F/S_{lateral}$ ratios of the additionally compacted pellets (with a lubricant layer) vary with compaction pressure. The application of a combined lubricant to the pellets eliminates their contact with the die and, hence, substantially decreases the pellet extrusion pressure and porosity.

The experimental results testify that there are two options for making long-length pellets that can be employed after considering the following well-grounded initial assumption: the experimental maximum $F/S_{lateral}$ ratio of the pellet does not depend on its height. This assumption in turn means that the extrusion pressure data obtained in this study using short dies can be recalculated for long-length pellets, for example, as follows. According to the first option, the TiH_2 samples are pressed in a lubricated one-piece die until a pellet with acceptable (~ 15 vol.%) porosity is produced. The pellet ~ 10 mm in diameter and ~ 160 mm in final height pressed at 700 MPa should have a surface area of ~ 50 cm². The experimental data indicate (Fig. 1b) that the extrusion pressure is ~ 10.2 MPa with 700 MPa compaction pressure and thus the pellet extrusion force is 5 t. The extrusion pressure can be equal to the compaction pressure (7 t) if the pellet is ~ 220 mm high.

If it is needed to reach greater density and height of the pellets and decrease the wear of dies, given the probability that the upper punch can break when bended in the pellet extrusion process, the more reliable second option including the following compaction stages can be considered. The pellet can be first pressed in a lubricated die at medium pressure (300–450 MPa) and, hence, extruded with lower force. It was found out that the pellet could be subjected to additional compaction at 800 MPa (and higher pressure) after being coated with a combined lubricant. In this case, the extrusion pressure is no more than 1–2 MPa. For a pellet 30 mm in diameter and 390 mm in height, the compaction force will be 21 t at 300 MPa and the extrusion force will be 1.1 t. Since this option substantially reduces external contact friction in additional compaction, it practically eliminates the decrease in density from the ends to middle part of the pellets, which is intrinsic to the pellets produced by single-stage double-action pressing [15].

The single-stage production of shortened pellets without additional compaction was studied in the second series of experiments using a water-soluble lubricant (based on glyceryl stearate) added to the TiH_2 powder in an amount of 1 wt.%. Following careful manual grinding of the components in a mortar, the mixture prepared as 5 g samples was pressed in a one-piece die with a working diameter of 10 mm and a height of 70 mm. The samples were pressed at 23°C. The lubricant was removed from the pellets with the known method [16], boiling in water for 1 h. After boiling, the pellets were subjected to forced drying at 105–110°C.

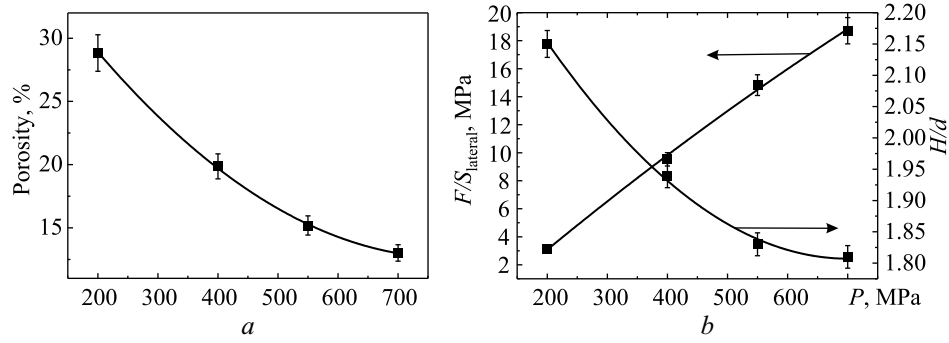


Fig. 4. Porosity (a) and F/S_{lateral} and H/d (b) ratios for the pellets produced from a mixture of the TiH_2 powder and water-soluble lubricant versus compaction pressure

Figure 4 shows how the porosity, extrusion pressure, and H/d ratio of the pellets produced from the TiH_2 powder mixed with a water-soluble lubricant vary with the compaction pressure. The data indicate that the mixture has already been effectively compacted at 550 MPa.

Figure 4b demonstrates that the F/S_{lateral} ratio significantly increases with higher compaction pressure. Therefore, it was studied how this ratio could be reduced with additional lubrication of the die (besides the water-soluble lubricant being introduced into the pellet) before loading the mixture sample. Figure 5 shows the porosity and F/S_{lateral} ratio of the pellets versus the compaction pressure in the die with the same water-soluble lubricant and adipose. The data indicate that additional lubrication of the die does not allow the extrusion pressure to be decreased to the value observed previously (Fig. 1b). This quantitative discrepancy of the results seems to be due to higher temperature (25–27°C) used in the second series of experiments. This decreased the viscosity of the lubricant [17] and thus accelerated its flow under load. In other words, higher compaction temperature made the lubricant to be extruded from the surrounding layer into the pellet volume (pores). Hence, when the lubricant layer lost its integrity, the pellet and the die came into contact, which increased the external contact friction and, accordingly, the extrusion pressure.

Considering the effect of compaction temperature on the rheological properties of the die lubricant, one can select a sufficiently viscous lubricant to remain intact in the gap separating the pellet and the die over the entire pressing process, promoting decrease in the external contact pressure. This option was implemented in additional compaction of the pellets (Fig. 2).

Nevertheless, even if this option is not considered, Figure 5 testifies that pressing of the titanium hydride powder with a water-soluble lubricant to produce billets at pressure no more than 550 MPa, without excessive increase in the pellet extrusion pressure, is quite acceptable.

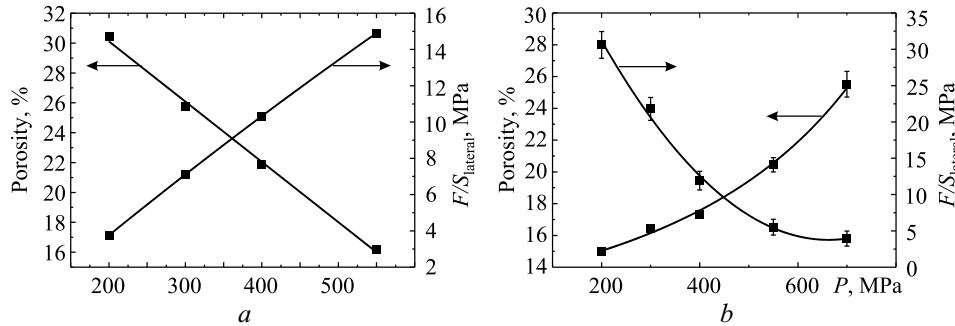


Fig. 5. Porosity and F/S_{lateral} ratio of the pellets produced from a mixture of the TiH_2 powder and water-soluble lubricant versus compaction pressure in the die with the water-soluble lubricant (a) and adipose (b)

Given the known dependence of the compressibility on pellet height [15], it should be assumed that experiments performed (in both this and other studies) with long-length pellets will provide more accurate information on the pressing process, which is required for commercial fabrication of parts. Moreover, it can be assumed that the procedures that we used for the pressing and additional compaction of pellets with $H/d > 4$ may prove to be useful in studying the compressibility of other metallic powders, including titanium and iron powders and associated mixtures.

Although there are no dies of great heights, our experiments with the pellets with the final H/d ratio being no more than 5/1 provide initial data indicating that long-length compacts can be produced from the titanium hydride powder. These compacts are further sintered to make rods of different sizes with the density corresponding to virtually compact titanium or its alloys.

The results obtained in the single-stage pressing of shortened pellets show that it is reasonable to find an acceptable water-soluble lubricant taking into account known formulations [18].

It should also be noted that the titanium hydride powder was compacted over a relatively narrow pressure range (100–800 MPa) in this experiment because of technical limitations. This is probably why the dependence of porosity on compaction pressure is linear (Fig. 1a). Considering the data reported in [19], it can be stated that the titanium hydride powder (and, in fact, many other powders) should be densified to 5000–6000 MPa to plot a complete dependence of the pellet density on compaction pressure.

CONCLUSIONS

We have studied single- and two-stage pressing of the titanium hydride powder in cylindrical dies to establish the extrusion pressure needed to determine whether long-length pellets of practically uniform density can be produced.

The extrusion pressure for pellets pressed from the titanium hydride powder in a lubricated die is one order of magnitude higher than the extrusion pressure for these pellets coated with a combined lubricant in additional compaction.

The drastic reduction in the extrusion pressure in the additional compaction process is due to a significant decrease in external contact friction. This increases the overall density of the pellets and eliminates the density difference along their height.

The resultant pellet extrusion pressure testifies that long-length compacts can be produced mainly by initial pressing of the titanium hydride powder in a lubricated one-piece die, application of a combined lubricant to the pellets, and additional compaction of the pellets in another one-piece die at higher pressure.

It has been established that single-stage pressing of the titanium hydride powder mixed with a water-soluble organic lubricant, to be further removed from the pellets by boiling in water, is feasible.

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