HOT DIE FORMING OF COMPACTED TITANIUM POWDER

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Titanium and its alloys are finding increasing application in engineering as constructional materials suitable for operation in corrosive environments. At present many titanium and titanium alloy constructional parts are produced by die forming from cast metal. However, this process comprises a number of intermediate operations, the last of which (die forming) is generally effected in several steps. This must inevitably result in lower operating efficiency, losses of metal, and higher overall cost of parts.

A process has now been developed for the manufacture of parts from titanium powder, in which production costs are lower than in processes involving the use of cast metal. The new process is based on the powder metallurgy technique combined with a high-productivity plastic working process - hot die forming. It consists essentially of the operations of cold pressing of preforms, their hot die forming, and final heat treatment.

In our study, an electrolytic titanium powder with particles -0.63+0.18 mm in size was chosen as starting material. Industrially produced titanium powders are normally composed of nonspherical granules. The particles of the powder used in our work were subjected to a statistical shape evaluation by the method of stereometric metallography [1], as a result of which their shape factor was found to be 0.8-0.87. Such powders can readily be shaped and sintered. The powder was cold pressed into compacts of 89-90% relative density, having the following dimensions (ram): d=30, H=30; d=60, H=70; and d=100, H=30. The 70-mm high compacts were produced by double-ended pressing.

The required preform volume was determined, taking into account the final porosity of the die formed parts, from the expression:

\[ V_p = V_c \frac{\gamma_c - \eta}{\gamma_\delta}, \]

where \( V_c \) is the volume of a cast metal preform, \( \gamma_c \) the relative density of the cast metal, \( \gamma_\delta \) the relative density of cold die formed preforms, and \( \eta \) the residual porosity after hot die forming.

The die forming of forgings, which were circular in plan, was preformed in a 1600-ton hot die forming crank press, using both open dies and closed flashless forgings dies with compensating holes. In addition, the die forming of similar parts was modeled under laboratory conditions in a 100-ton crank press. In our experiments, green and sintered preforms and, to obtain a basis for comparison, cast titanium were subjected to die forming (Figs. 1 and 2). Die forming (force vs displacement) diagrams were recorded by means of standard strain measuring apparatus. The initial and final die forming temperatures were measured with an optical pyrometer. Titanium and its alloys are amenable to hot plastic working at temperatures somewhat lower than those required for the plastic working of steel. One of the structural constituents of titanium is the \( \beta \) phase, which has the bcc lattice and is more ductile than the other constituent, the hexagonal \( \alpha \) phase [2]. In our work, before the die forming operation, the preforms were heated in a resistance furnace provided with an argon atmosphere at 950°C for 10-15 min and in induction heaters for 3-5 min. Because of the low thermal conductivity and diffusivity of such preforms, during the initial period of heating appreciable temperature gradients may arise in them, setting up thermal stresses. In view of this, the

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Fig. 1. Diagrams of hot die forming of cast titanium (1) and compacted titanium powder (2) in 100-ton crank press. In Figs. 1 and 2, P is the forming load, p the forming pressure, S the displacement of the press die slide, and α the angle of revolution of the press crankshaft.

Fig. 2. Diagrams of hot open (1) and closed (2) die forming of compacted titanium powder in 1600-ton hot die forming crank press.

Fig. 3. Microstructures of parts from titanium powder, × 200: a) after hot die forming; b) after annealing.

TABLE 1. Mechanical Properties of Parts Produced by Hot Die Forming from Electrolytic Titanium Powder and Cast VT1-00 Titanium Preform

<table>
<thead>
<tr>
<th>Density of starting compacts, g/cm³</th>
<th>Die forming temp., °C</th>
<th>Subsequent heat treatment</th>
<th>Density of parts, g/cm³</th>
<th>UTS, kg/mm²</th>
<th>elong., %</th>
<th>RA, %</th>
<th>Imp. str., kg·m/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.24</td>
<td>950—1000</td>
<td>Anneal at 750°C, 3 h, pressure 2 · 10⁻⁴ mm Hg</td>
<td>4.49</td>
<td>40—42</td>
<td>26—28</td>
<td>56—58</td>
<td>11—12</td>
</tr>
<tr>
<td>4.34*</td>
<td>950—1000</td>
<td>The same</td>
<td>4.50</td>
<td>43—45</td>
<td>28—30</td>
<td>58—60</td>
<td>12—14</td>
</tr>
<tr>
<td>4.505 †</td>
<td>Ti—60</td>
<td>—</td>
<td>4.505</td>
<td>30—45</td>
<td>25</td>
<td>55</td>
<td>12</td>
</tr>
</tbody>
</table>

*The compacts were sintered in a vacuum of 2 · 10⁻⁴ mm Hg at 1200°C for 3 h.
†Cited after [3].