Fig. 2
ABSTRACT OF THE DISCLOSURE

A molding device for compacting metal powders into tubular or rod shapes is described, said device having an inner electrical conductor which is shaped to provide a non-conductive gap of desired shape of the article desired to be produced, an outer electrical conductor which completely surrounds the inner conductor, is insulated from it, and is clad with a nonmagnetic metallic sleeve, and said conductors being connected to a power supply and switching means.

The invention described herein was made in the course of, or under, Contract W-7405-ENG-36 with the U.S. Atomic Energy Commission. This application is a continuation of S.N. 372,426, filed June 3, 1964.

This invention relates to a device for compacting metal powders and in particular to a device that uses a magnetic field produced in a coaxial conductor to consolidate the metal powders into tubular or rod shapes. The advantage of this device lies in the fact that extremely high pressures are attainable over extremely long lengths of compacted powdered material. The nature of the coaxial configuration is such that the magnetic field is uniformly strong. This prevents degradation of density or deformation of materials compacted using this technique and device indicate improvement over conventional hydrostatic techniques with peak pressures attainable in the range of 50,000 pounds per square inch. A decided advantage of this process is that except for explosive compaction techniques lies in the fact that magnetic techniques are more reproducible. Another advantage of this device is that extremely intricate shapes may be produced, these shapes being dictated by the mandrel geometry.

In addition to all the aforementioned advantages, the magnetic compaction technique of this invention has additional advantages in that it is practical to perform the compaction operation in a limited shop area.

It is an object of this invention to provide a device for compaction of metal powders into rods, tubes, or any desired shape and having a green density of at least 60 percent of theory.

Embodiment of this invention will now be described by way of example with reference to the accompanying drawings wherein:

FIGURE 1 is a sectional view of the coaxial device in a configuration used for consolidating metallic particles into a tubular shape.

FIGURE 2 is a simplified electrical schematic of the capacitor bank power supply and coaxial load, and the ignitron switching header.

FIGURE 3 is an enlarged cross-sectional view of the upper end of FIGURE 1 and allows greater detail to be shown.

FIGURE 1 depicts the outer conductor 9 which has been clad with a nonmagnetic stainless steel sleeve 10 while the inner conductor is an annealed copper tube 7 which acts as the "pusher" and confinement for the powders to be compacted. Electrical connections are made to the copper tube by means of tapered copper plugs 2 which are driven into the inner conductor 7 to produce a good electrical contact. The top plug 2, which is held in place by brass lock nut 1, also shorts across the annular gap 8 between the inner and outer conductor thereby completing the current path. The annular gap between the inner and outer conductor must be insulated with a dielectric 12 (also see FIG. 3) of sufficiently high breakdown voltage so as to prevent any arcing which might occur between the said conductors. Any arcing which does occur between these conductors significantly decreases the efficiency of the process. Vinyl tubing has been found to be an effective means of insulating these conductors. This insulation must be, however, held to a minimum thickness if the efficiency is to be kept high. The powder 6 is placed in the annular gap created between the inner conductor 7 and the mandrel 8. This mandrel is held in place in the center of the tube with nicarta plugs 4 which are bored to hold the terminal ends of the mandrel. Tight fitting rubber plugs 3 are inserted over the mandrel holders to serve the dual purpose of creating leaktight seals and acting as electrical insulation between the shorting plugs 2 and the mandrel 8. The coaxial conductor is then firmly gripped to a two-way header 13 and 16 fabricated from aluminum, and is connected to the coaxial cables 14 which are in turn connected to a capacitor bank (not shown). Upon discharging the capacitor bank, the current is carried up the inside of the outer conductor 9, and back to ground 19, through the inner conductor 7 and a copper tube 11 and ground lead 19. The magnetic fields generated by this high current are repelling to each other. Due to the fact that the inner conductor has a lower mechanical strength than the outer conductor, the inner conductor is crushed by the magnetic field.

FIGURE 2 shows the power supply, the capacitor bank, ignitron switching header, and the coaxial load. The bank which is being used to supply this coaxial device with electrical power has a capacitance of 715 microfarads at 40 peak voltage of 20 kV. The bank consists of 48 capacitors with switching accomplished through 16 ignitron tubes with a single trigger ignitron. The peak current produced using the coaxial load configuration is approximately 1200 ka. Using this particular system it is possible to develop instantaneous peak pressures which are in excess of 30,000 pounds per square inch.

FIGURE 3, in addition to showing all the components shown in the top terminal in FIGURE 1, shows a thin walled (0.010 inch) cellulose acetate sack 18. The cellulose acetate sack contains the metal powder and is inserted into the copper inner conductor 7 which is slipped inside a vinyl tubing 12. The mandrel is lubricated with a thin film of silicon grease with the said grease mandrel being slipped inside a polyethylene or Teflon shrink tube 17.

Operating principles

The above described device uses the ability of a copper conductor carrying very high pulse currents (in the range of 10⁹ to 10¹⁰ amperes) to crush itself due to the magnetic field generated around the conductor. The time scale for the compacting operation is of the order 10⁻⁴ to 10⁻⁵ seconds, determined by the ringing frequency of the power supply system. The energy stored in the capacitor bank is of the order of 10⁸ joules or watts-seconds. This magnetic field is confined in the annular gap between the inner and outer conductors such that the field acts as if it were a compressed gas tending to crush
the inner conductor or to expand the outer conductor depending on the geometry of the coaxial device. In the above-described device, the outer conductor is prevented from bulging due to the stainless steel sleeve surrounding it. A nonmagnetic sleeve material that has structural strength must be used. The outer cladding also must be of a nonmagnetic material, e.g., brass, aluminum, or austenitic stainless steel so as to prevent the magnetic field from escaping the annular gap between the inner and outer conductor.

Materials compacted

Tubular shapes have been magnetically compacted using tungsten, molybdenum, tungsten-uranium oxide, and molybdenum-uranium oxide powders as starting materials. In all cases, no binders were added to the powders. The green density and strength of the "as compacted" tubes allows handling prior to sintering even without the use of binders. In the case of molybdenum, various sizes of particles have been compacted and in all cases the green density is considerably greater than the density produced using hydrostatic techniques.

The technique used for filling the copper "pusher" prior to compaction consists of centering the mandrel in a thin walled cellulose acetate tube (FIGURE 3). The cellulose acetate tube is used to protect powders such as molybdenum and the uranium oxide loaded cermets from acid attack during the dissolution of the copper "pusher" after the compaction. Packing of the loose powder into the continuous acetate sack is accomplished with an ultrasonically vibrated table. The nature of this invention is such that uniform powder packing is mandatory; however, it is not necessary to have a high packed density. If the packed density is not uniform, the compacted tube will not be uniform either. Although FIGURE 1 shows a steel mandrel being used to form a powder compacted tube, fusible alloy mandrels may be used, but since the modulus of these materials is extremely low, it is difficult to keep the mandrel centered and consequently the compacted tube will not be concentric.

After the powders have been compacted, the shorting plugs are still in the inner conductor 7. These end plugs and vinyl insulation (FIGURE 3) are removed and the mandrel is extracted by either manual pulling or, in some cases, by application of a draw bench. The copper "pusher" should not be removed until the mandrel has been extracted from the compact. The copper sheath gives the compact enough mechanical strength to prevent the development of compression cracks in the green tube. In order to facilitate the removal of long mandrels from compacted tubes, the steel mandrel is first lubricated with a thin film of silicone grease. The greased mandrel is subsequently slipped inside a polyethylene or Teflon "shrink" tube (FIGURE 3). This tubing shrinks upon heating due to plastic memory and thus prevents any lubricant from coming in contact with the compacted metal powders. The lubricant on the mandrel allows the mandrel to be extracted easily while the "shrink" tube is subsequently removed from the compact by the application of heat. A temperature of 150°F is sufficient to shrink the plastic tube away from the green compacted interior 10 diameter of the tube. The green powder compact is separated from the copper "pusher" by means of acid etching.

Compaction of powder metals up to 30 inches in length has been produced using the device described herein, and longer lengths are readily attainable. As noted from Table I above, molybdenum tubes having a 0.40-inch outer diameter by 0.225-inch inner diameter and 5 to 10 inches long were compacted using 4.5 micron molybdenum powder without the aid of binder materials. This molybdenum compact has a theoretical density in excess of 97%. Other sintered densities for molybdenum +uranium oxide and tungsten +uranium oxide are listed in Table I where the uranium oxide material had an average particle size of 4.2 microns. Although the data presented in Table I was obtained without the use of binders in conjunction with the magnetic compacting method, the inventors have done a limited amount of work using well known epoxies as binders. The epoxies appear to be excellent binder materials from the standpoint of low residue upon sintering and high strength in green cured state.

In particular, although the foregoing specification only describes a device for forming tubular shapes of metal powders, the removal of the mandrel from this device allows solid rods to be formed. Thus, the foregoing illustrations of the present invention are not intended to limit its scope which is to be limited entirely by the appended claims.

What is claimed is:

1. A molding device for compacting metal powders into tubular or rod shapes comprising in combination:
   (a) an inner electrical conductor which is shaped to provide a molding cavity and having the general shape of the article desired to be produced,
   (b) an outer electrical conductor that completely surrounds the inner conductor and which is electrically insulated from said inner conductor by a thin dielectric material,
   (c) said outer conductor being clad with a nonmagnetic metallic sleeve,
   (d) a power supply capable of supplying 10⁸ amperes for a short circuit from 10⁻⁴ seconds, and
   (e) tapered shorting plugs which electrically connect the outer conductor to the inner conductor so as to allow current to pass from the power supply to

<table>
<thead>
<tr>
<th>Material</th>
<th>Particle Size</th>
<th>Percent of Theor. Green Density</th>
<th>Sintered Properties 1</th>
<th>Sintered Properties 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo compacted over steel mandrel</td>
<td>4.5μ</td>
<td>70.06</td>
<td>0.69</td>
<td>5.67</td>
</tr>
<tr>
<td>Mo compacted over a copper alloy mandrel</td>
<td>4.5μ</td>
<td>80.5</td>
<td>1.6</td>
<td>6.32</td>
</tr>
<tr>
<td>Mo-40% V/UOs compacted over a steel mandrel</td>
<td>7.5μ</td>
<td>10</td>
<td>0.22</td>
<td>2.22</td>
</tr>
<tr>
<td>W-40% V/UOs compacted over a steel mandrel</td>
<td>3.75μ</td>
<td>98.4</td>
<td>15.29</td>
<td>0.12</td>
</tr>
<tr>
<td>W-compacted over a steel mandrel</td>
<td>3.75μ</td>
<td>98.4</td>
<td>2.49</td>
<td>10.31</td>
</tr>
</tbody>
</table>

1 Sintered at 1,700°F in 3 hrs for 2 hours.
2 Sintered at 2,000°F in vacuum for 2 hours.

TABLE 1.—DENSITY OF SINTERED REFRACTORY METAL TUBING FABRICATED BY MAGNETIC COMPACTION
5. The device of claim 1 in which said sleeve material is selected from the class consisting of austenitic stainless steel and aluminum.

6. The device of claim 5 in which said sleeve material is austenitic stainless steel.

7. The device of claim 5 in which said sleeve material is aluminum.

8. The device of claim 1 in which the mandrel is held in place by tight fitting rubber plugs which are inserted over the terminals of the mandrel creating leak-tight seals and acting as electrical insulation between the shorting plugs and the mandrel.

9. The device of claim 2 in which the mandrel is encased in a polyethylene tube.

10. The device of claim 1 in which the current is discharged through a two-way header that has means to grip the inner and outer conductor.

References Cited

UNITED STATES PATENTS

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3,171,014 2/1965 Ducate.

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