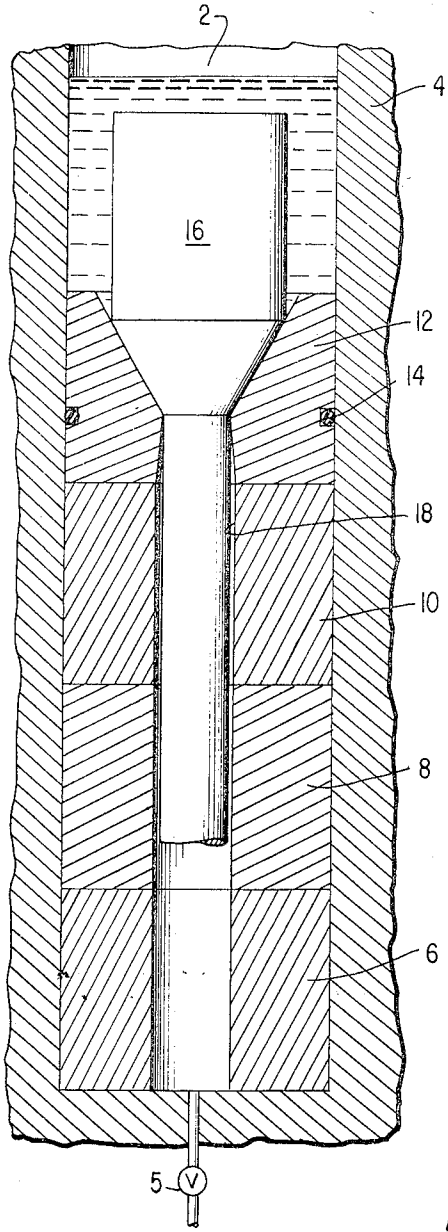
Dec. 9, 1969 A. BOBROWSKY ET AL. 3,482,424

PROCESS AND APPARATUS FOR FORMING AND WORKING METALS UNDER PRESSURE

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FIG.1



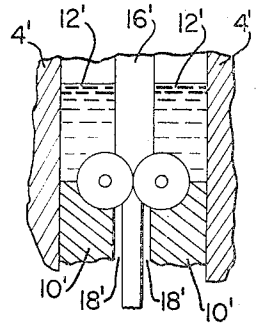


FIG.1A

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PROCESS AND APPARATUS FOR FORMING AND WORKING METALS UNDER PRESSURE

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Int. Cl. B21c 27/00

U.S. Cl. 72—60 17 Claims

ABSTRACT OF THE DISCLOSURE

The present invention relates to a process and apparatus for forming and working metals under pressure in which a billet is seated in a die by any of a number of known means. The die-cum-billet is placed a calibrated distance above the level of a fixed support, which support may be one or more hollow cylindrical supports resting on a plunger in the lower part of the chamber or on a plug, or, in a further embodiment, the die can be seated at the bottom of the chamber directly on a plug having a means therein for withdrawing the extrusion. The plunger can be slideable and unsupported by the bore while the plug, if desired, can be threaded into a counterbore at the end of the bore. When pressure is increased in the high pressure portion of the chamber, the die-cum-billet assembly moves downwardly toward the receiving chamber with the pressure being approximately equal in both chambers. Leakage is prevented between the die and the pressure chamber wall by any of a number of conventional means, such as O-rings. When the die reaches the fixed support, its travel ceases and further pressurization of the high pressure liquid above it continues. At a sufficiently high value of the upper chamber pressure, the billet is forced through the die into the receiving chamber. The distance between the die at the start of its motion and the support can be such that any desired pressure can be achieved in the receiving chamber provided that pressure can be applied to the upper chamber. The emergence of the emitted extrusion from the die displaces liquid and tends to raise the pressure in the receiving chamber. A relief valve is provided at the bottom of the receiving chamber, the valve consisting essentially of a port, a ball which seats against the port, and a spring to press the ball against the port. When a preset value of pressure is reached, the fluid pressure overcomes the spring pressure against the ball and a controlled leakage of fluid is permitted from the receiving chamber. The relief valve may, of course, be replaced by any other conventional means known to the art.

This application is a continuation of Ser. No. 427,909, filed Jan. 25, 1965.

The invention utilizes the phenomenon that metals which are ordinarily brittle at room temperature become ductile under high pressure. Materials such as metals, plastics, and composites of powdered materials with binders have been formed in long thin geometries such as rods, wires, strips and tubes from the same but larger shapes or from other shapes by deforming the outer surface with moving parts, e.g. rolling, or with stationary parts such as dies, e.g. drawing and extrusion. Sometimes the material to be formed has been encased in a sheath

with another material, i.e. clad, prior to the forming process and then both materials have been formed as an integral unit.

The forcing of material through an aperture of a die is termed drawing when a tensile force pulls the material through the die, and is termed extrusion when either the material is pushed through the aperture or apertures of the die by a ram, i.e. forward or direct extrusion, or when a die is pushed into the material so that the material is forced through an aperture or apertures in the die, i.e. indirect or backward extrusion. Variations on the extrusion process exist in the fabrication of tubing where a mandrel is placed in a hole in a material so that the material is pushed through an annular opening between the mandrel and the die, and in the process of impact extrusion where the material is struck a blow by a hammer and thus forced through a die or between a mandrel and a die.

In both types of extrusion, the material to be extruded, in its initial geometric shape, is thermed a billet. The billet is in contact on its lateral faces with a chamber wall or chamber and when the ram pushes against the billet to force it through the die, the billet in turn exerts pressure on the chamber wall. This pressure results in a frictional force of the billet on the chamber wall, resisting movement of the billet. With long billets, the pressure on the chamber wall may be so great as to result in a frictional force that completely prevents extrusion. The material leaving the die is termed the extrusion or the extruded material.

It is known that wire-drawing can be performed with the die and material completely immersed in liquid under pressure. The fluid pressure increases the ductility of the wire while being drawn, thereby enabling greater reductions in area to be made by successive draws under pressure for a given final ductility of wire than could be obtained by drawing the wire at atmospheric pressure. Further, stronger wire is produced by drawing under pressure.

It is also known that material can be extruded through a die by a fluid under pressure pressing on the billet. This process is termed fluid extrusion and both copper and steel wire have been so extruded although difficulty was experienced with "spitting out of metal in gulps." This fluid extrusion was performed at room temperature although in principle it could have been performed at other temperatures. Further, it is known that the fluid extrusion process can be combined with the drawing of wire under pressure so that both processes can be performed simultaneously.

It is also known that material can be fluid-extruded into a receiving chamber containing fluid under pressure and that tubing and profiled shapes can be fluid-extruded as well as solid round shapes such as bars, rods, and wires. Tubing was formed by placing a strong mandrel in a pierced billet such that the top of the billet was sealed against fluid pressure, and causing both the mandrel and the billet to be fluid-extruded through a die, thus reducing the billet wall thickness.

It is also known that ram extrusion can be performed in a manner such that the extruded material enters a chamber filled with fluid under pressure. This use of fluid under sufficient pressure reduces or eliminates cracking of the extruded material in those cases where cracking might otherwise occur without the use of a fluid-pressurized region to receive the extruded material.

There are many advantages of fluid extrusion and fluid-

to-fluid extrusion over ram extrusion; some of these advantages are:

(a) the process can be performed at room temperature,
(b) because of a, materials that oxidize easily can be fluid-extruded while cold,
(c) billets do not touch the chamber walls, thereby reducing friction,
(d) a film of lubricant forms between the billet and the die, virtually eliminating die wear, and reducing friction,
(e) low-angle dies are used, reducing work of deforming the metal in the die,
(f) pressures for fluid extrusion are less than for ram extrusion because of c, d, and e,
(g) billets of unlimited length are possible because of c,
(h) the fluid pressure can be used to support the die; hence thin die walls can be used,
(i) billets are not subjected to buckling loads because of hydrostatic-pressure conditions, so that flexible billets can be used, such as wire,
(j) greater reductions are possible for fluid extrusion than for ram extrusion, because of the increase of ductility in a pressurized environment,
(k) brittle materials can be fluid-extruded, provided the pressure level is above that for brittle-to-ductile transition,
(l) no or very little pipe appears at the end of the extrusion,
(m) the entire billet can be extruded, if desired,
(n) nosing of the billet is not necessary, minimizing wastage,
(o) hardness traverses on fluid-extruded metal show very uniform properties across the cross-section, in contrast to ram extrusion,
(p) the extruded material is more uniform in properties along the length than for materials extruded at elevated temperatures, because there is no variation in temperature due to cooling during the extrusion process,
(q) because of a, it is not necessary to hurry to extrude a hot billet before it cools,
(r) repeated reduction or forming passes may be made, and
(s) for a given material, higher strength can be achieved than by any other metal working method and higher ductility for a given strength.

The chief mechanical parameters influencing deformation of metals under pressure are:

(a) the yield (strength) criterion, and
(b) the ductility (deformation) criterion.

It is well known that stresses on the surface of a volume of material can be viewed with respect to a set of three straight right-handed axes, termed axes of reference, which are mutually at right angles, and with identical increments of equal spacing along all axes. Such axes are frequently called right-handed rectangular Cartesian axes. Planes normal to these axes are termed parametric planes. A set of six planes, two each normal to only one axis, and each pair of planes thus obtained being spaced equally, form the faces of a contained cube. This cube can be imagined to constitute an element of volume of material. The size of the element is taken as so small that stress on any face is essentially constant across that face, but not so small that variations in material property due to individual atoms are discernible across any face.

The stress on any face, termed the combined stress, is, in general, not normal to that face. The combined stress on each face can be divided into three components parallel to the axes of reference. The component of stress normal to the face is termed a direct or normal stress, and the two components parallel to the face are termed shear stresses.

It is known that for any state of stress on an element of volume of material, a set of reference axes can be chosen of orientation such that all shear stresses are zero. For such orientation, the direct stresses are termed principal stresses. The three principal stresses for any state of stress are here termed A, B, and C.

If a specimen of material is subjected to direct stress in one direction only, termed uniaxial stress, the specimen deforms under the stress. For values of stresses below a number Y or F characteristic of a given material, the deformation is elastic only, i.e., the deformation disappears and the specimen resumes its original size and shape after the stress is removed.

If for uniaxial stress exceeding Y, the deformation is partly plastic, i.e., the material yields plastically so that it possesses a different size and shape than it did originally, after stress is removed, the material is said to be in a ductile state. Y can be termed the yield stress. For simplicity, it is here assumed that the yield stresses are equal in uniaxial tension and uniaxial compression.

If at a uniaxial stress F, the material fractures with no previous plastic flow, the material is said to be in a brittle state. F can be termed the fracture stress. In general, the fracture stress is different in uniaxial tension and uniaxial compression. Some materials fracture in tension without yielding, but flow plastically in compression.

If the state of stress is not uniaxial, a yield criterion is required to define the manner of combination of the stresses so that a known state of stress produces yield. The first assumption usually made is that the hydrostatic component of stress, S, to a first approximation, does not produce yield, regardless of the magnitude of S. The hydrostatic component of stress, S, is defined to be $(A+B+C)/3$. Two yield criteria are in common use, one the maximum-shear-stress criterion and the other the second-deviatoric-invariant criterion. The maximum-shear-stress criterion states that yield occurs when the absolute value of the maximum shear stress, defined as half the difference of the largest and smallest principal stresses, exceeds the absolute value of $Y/2$. The second-deviatoric-invariant criterion is a little more complex. Deviator stresses, defined as $a=(A-S)$, $b=(B-S)$, and

$$c=(C-S)$$

are computed. The yield is said to occur when the second-deviatoric-invariant, J, defined as $(a^2+b^2+c^2)$ exceeds $2Y^2/3$.

Regarding the ductility criterion, it is known that the maximum distortion, defined as the largest percentage permanent change in dimension without fracture in any length on a specimen of material subjected to uniaxial stress until fracture ensues, is increased if the material is in a pressure environment. Further, it is known that adequate increase in pressure can cause a material to alter from a brittle to a ductile state. The ductility criterion is that pressure required to permit a desired given distortion to occur without fracture or undue loss of desirable ductility in the distorted specimen.

Thus, it is apparent that an increase in environmental pressure can permit a given material to be formed without fracture, whereas the same forming operation attempted at atmospheric pressure could result in fracture. The pressure employed must be high enough to permit the yield criterion to be exceeded in the metal to be formed, so that the material will deform permanently.

In the process of fluid-to-fluid extrusion, a metal billet is forced by fluid pressure through an aperture in a die into a region containing fluid under lower pressure. The die shapes or sizes the billet to the shape and/or size of the emitted extrusion. In ordinary practice, the upper or high fluid pressure is generated by a moving arm and/or a pump. For the highest pressures, a moving ram is required. The pressure in the lower chamber may be generated in a similar manner. A difficulty arises in that the emitted extrusion may have to be removed from the receiving chamber through a seal, in which case it is difficult to utilize an inlet for pumped liquid and extremely difficult to employ a moving plunger.

The process of the present invention of permitting fluid-to-fluid extrusion to occur into a receiving chamber results in a great simplification of the process, making possible economical commercial utilization thereof.

In a further feature of the present invention, the discharge port is of such size that the emitted extrusion passing into the port acts as a seal so that no further loss in pressure or liquid will occur in the receiving chamber. This is accomplished by causing the extrusion to force the ball to the side and out of the way of the extrusion while it passes through the center of the spring which supports the ball. This process of displacing the ball is aided by providing a small eccentric point or wedge on the most forward part of the emitted extrusion, the point or wedge being provided on the interior billet prior to placing it in the die.

The invention will be further illustrated by reference to the accompanying drawings in which FIGURE 1 is a schematic view showing a pressure chamber for the forming and working of metals in accordance with the present invention and FIGURE 1A is a fragmentary sectional view of a similar apparatus using rolls instead of a die to effect deformation.

Referring to the drawings, a cylindrical bore **2** is shown in a block of tool steel **4**, which bore is closed at the lower end **5** thereof by a conventional relief valve **5**. Three annular spacer-supports **6**, **8**, and **10**, respectively, of tool steel are seated in the bore and a die **12** is seated on the annular spacer-supports **10**. The die is provided with a seal **14** to seal the die against the wall of the extrusion chamber or bore **2**. A billet of metal **16** to be formed and/or worked is shown seated in the die and partially extruded therethrough. There is a small clearance **18** between the extrusion and the inner walls of the spacer-supports **6**, **8**, and **10**. This small clearance facilitates "catching," i.e., deceleration of the extrusion after it has passed through the die.

In operation, the cylindrical bore **2** is filled with a suitable pressure medium, not shown in the drawing, such as gasoline, pentane, petroleum ether, and the like, and pressure is generated on the pressure medium by means of a pump and/or a hydraulic ram, not shown. It is not necessary that the pressure medium be a liquid and, at the high pressures employed, the pressure mediums can become soft solids; it is necessary only that a pressure medium be employed which is softer than the material to be extruded and which is capable of transmitting hydrostatic pressure. Pumps can be reliably employed to generate pressures as high as 150,000 p.s.i. and in order to generate higher pressures a hydraulic intensifier is required.

The apparatus of the present invention is particularly advantageous in that the pressure chamber has a uniform diameter. Pressure chambers are employed at the highest level of stress and any change in the cross-section of such a chamber increases the stress. The uniform diameter of the pressure chamber of the apparatus of the present invention also is advantageous in that if it wears and must be enlarged, it is much easier to enlarge it if no shoulder is present therein. The chamber must from time to time be enlarged due to wear since the parts slide therein and wear results.

The ratios of the diameters of the bore of the pressure chamber and the bores in the spacer-supports is not critical and may be in the range of about 10:1 to about 10:8. The length of the pressure chamber and the number of spacer-supports also is not critical and the chamber may be of any desired length. Any number of spacer-supports may be employed as desired and the spacer-supports may be made as a single block instead of three spacer-supports as shown in the drawing. The bore in the center of the spacer-supports can be circular or of any other cross-sectional configuration.

It is not necessary that liquid be present below the die during the extrusion operation and, in this case, the process is referred to as fluid extrusion but when liquid is present below the die, it is termed fluid-to-fluid extrusion.

The process operates over a wide range of pressure, i.e., from about 10 p.s.i. to 1.5 million p.s.i. and good results have been obtained at pressures of about 500,000 p.s.i. The upper limit of pressure is determined primarily by the strength of the material in which the pressure chamber is formed

The process can be operated at any temperature which is not sufficiently high to affect the strength of the material in which the chamber is formed.

In some cases, it has been found desirable to employ a pressure medium which has the property of favorably altering the ductility of the metal being worked. For example, it has been found advantageous to employ an aqueous solution of sulfuric acid in the working of 98 percent pure beryllium.

In a modification of the present invention shown in FIGURE 1A in which the primed numerals designate structure corresponding to that designated by the unprimed reference numbers in FIGURE 1, the die can be replaced by a pair of rolls through which the metal to be worked is passed and, in this case, a means is required to pull the metal between the rolls or, alternatively, the rolls can be driven. This modification is only exemplary of the various means which may be employed to reduce the size and/or shape of the billet and others can be employed with the basic construction of the pressure chamber having a uniform diameter and one or more spacer-supports therein.

Also, the spacer-supports can be made with a large clearance between the peripheries thereof and the wall of the pressure chamber, whereby tubing can be extruded.

The invention will be further illustrated by reference to the following specific example:

EXAMPLE

A chamber of substantially constant cross-section, equal to 0.490 inch diameter, was bored in a block of tool steel and a restraining plug mounting a slideable high-pressure seal was affixed to the pressure chamber in a manner such that the plug supported the seal in the 0.490 inch bore by preventing axial motion of the seal. The seal itself preventing leakage of liquid from the bore.

The bore was then filled with gasoline and six annular spacer-supports were dropped into the bore, displacing the gasoline. The spacers were each approximately one inch long, 0.489 inch in outer diameter, and 0.135 inch in inner diameter. A die, the maximum diameter of which was 0.489 inch and which mounted thereon a pressure-sealing means which created a frictional force of approximately 3 pounds between the die and the chamber wall, was inserted in the chamber in a manner such that the die rested in the chamber approximately ⅛ inch above the top-most spacer-support. A billet of commercially pure aluminum, having a diameter of 0.375 inch and a pointed lower end, was placed in the die in a manner such that the conically pointed end of the billet rested in the conical entrance to the die. A preliminary fluid seal between the billet and the die was established by coating the conical point of the aluminum billet with a wax. The minimum diameter of the aperture in the die was 0.125 inch. A hollow cylindrical guide was slipped into the bore so that it rested on the die and tended to prevent the billet from tipping in the die. This guide had an outer diameter of 0.489 inch and an inner diameter of 0.385 inch.

Some gasoline was removed from the bore so that the remaining gasoline filled the bore to within one half inch of the top thereof. A slideable high-pressure seal was then inserted into the upper part of the bore to pressurize the gasoline. A ram was forced against the upper slideable pressure seal, the reaction force of the entire assembly being taken on the lower-most portion of the pressure chamber. The ram forced the upper slideable pressure seal into the bore and thereby pressurized the liquid above the billet and

die assembly. Since the frictional force between the die assembly and the chamber wall was only about 3 pounds, the die began to move downwardly under the force of the pressurized liquid above the die so that the pressure below the die differed from the pressure above the die by approximately 3 pounds. This motion continued until the die abutted against the top of the spacer-supports at which point further motion of the die downwardly in the chamber was restrained by the spacer-supports.

The pressure continued to build up above the billet until a pressure differential was achieved such that the billet of aluminum began to extrude through the die. In this case, the extrusion of the aluminum through the die caused the pressure below the die and surrounding the spacer-supports to increase so that the upper pressure was increased continuously during the extrusion process as was the lower pressure. The pressure in the bore of the spacer-supports was approximately 100,000 p.s.i. at the time the die came to rest on the top of the spacer-supports. The pressure differential required for extrusion in this case was about 50,000 p.s.i. and this differential remained approximately constant as the pressure increased. Finally, with an upper pressure of about 350,000 p.s.i. and a lower pressure of about 300,000 p.s.i., the complete billet was forced into the bore of the spacer-supports.

The downward motion of the aluminum extrusion, which was initially rapid, was slowed by the shear stresses set up between the billet and the inner diameter of the spacer-supports so that the billet velocity was reduced very nearly to zero before the billet could strike the slideable pressure seal at the bottom of the pressure chamber.

The upper ram was then withdrawn, reducing fluid pressure essentially to zero in the entire chamber. The restraining plug at the bottom of the chamber and the lower slideable metal seal were removed, after which the spacer-supports, extrusion, and die were removed through the bottom of the chamber. The upper slideable pressure seal was then removed from the top of the chamber.

It will be obvious to those skilled in the art that many modifications may be made within the scope of the present invention without departing from the spirit thereof, and the invention includes all such modifications.

What is claimed is:

1. An apparatus for forming and working metals under pressure which comprises: a chamber of uniform internal diameter having a closed end and constructed to withstand high internal pressures; at least one annular spacer-support disposed within said chamber at the closed end thereof and supported by said end; a die seated on said spacer-support and disposed within said chamber, said die dividing said chamber into two distinct portions, an entry portion for subjecting the billet to hydrostatic forces on the entrance side of the die and an exit portion for receiving the extrusion, there being a small clearance between said spacer-support and the emergent metal so that fluid shear stresses can act to control the speed of the emergent metal; a medium in said chamber on at least the entry side of said die, said medium being capable of transmitting hydraulic pressure; and means for passing metal through a bore in said die to thereby change of the size of the metal.

2. An apparatus according to claim 1 in which the medium capable of transmitting hydraulic pressure is present in said chamber on both sides of said die.

3. An apparatus according to claim 1 in which a plurality of annular spacer-supports are employed.

4. An apparatus for forming and working metals under pressure which comprises: a chamber of uniform internal diameter having a closed end and constructed to withstand high internal pressures; a plug located within said chamber and at the closed end of said chamber; at least one annular spacer-support disposed within said chamber, seated on said plug and supported by said plug; a die seated on said plug and disposed within said chamber, said die dividing said chamber into two distinct portions, an entry portion for subjecting the billet to hydrostatic forces on the entrance side of the die and an exit portion for receiving the extrusion, there being a small clearance between said spacer-support and the emergent metal so that fluid shear stresses can act to control the speed of the emergent metal; a medium in said chamber on at least the entry side of said die, said medium being capable of transmitting hydraulic pressure; and means for passing metal through a bore in said die to thereby change the size of the metal.

5. An apparatus for forming and working metals under pressure which comprises: a chamber of uniform internal diameter having a closed end and constructed to withstand high internal pressures; at least one annular spacer-support disposed within said chamber at the closed end thereof and supported by said end; metal working means disposed within said chamber and supported by said spacer-support, said metal working means dividing said chamber into two distinct portions, an entry portion for subjecting the billet to hydrostatic forces on the entrance side of the metal working means and an exit portion for receiving the extrusion, there being a small clearance between said spacer-support and the emergent metal so that fluid shear stresses can act to control the speed of the emergent metal; a medium in said chamber on at least the entry side of said metal working means, said medium being capable of transmitting hydraulic pressure; and means for passing metal through said metal working means to thereby change the size of the metal.

6. An apparatus according to claim 5 in which the metal-working means comprises a pair of rolls.

7. An apparatus according to claim 6 in which the rolls are driven.

8. An apparatus according to claim 5 in which the means for supporting the metal-working means in the chamber comprises a plug in one end of the chamber.

9. An apparatus according to claim 5 in which the medium capable of transmitting hydraulic pressure is present in the chamber on both sides of the metal-working means.

10. A process for forming and working metals under pressure which comprises: passing a billet through a metal working means supported in a chamber of uniform internal diameter along its entire pressurized length and having a closed end and constructed to withstand high internal pressures and then passing said billet as it emerges from the metal working means through at least one annular spacer-support disposed within said chamber at the closed end thereof and supported by said end, said metal working means dividing said chamber into two distinct portions, an entry portion for subjecting the billet to hydrostatic forces on the entrance side of the die and an exit portion for receiving the extrusion; controlling the speed of the emergent metal by providing a small clearance between said spacer-support and the emergent metal so that fluid shear stresses can act to control the speed of the emergent metal, there being a medium in said chamber capable of transmitting hydraulic pressure.

11. A process according to claim 10 in which the billet is passed successively through the metal-working means and a support for the metal-working means.

12. A process according to claim 10 in which the medium capable of transmitting hydraulic pressure is present in the chamber on both sides of the metal-working means.

13. A process according to claim 10 in which the metal-working means is a die.

14. A process according to claim 10 in which the metal-working means is a pair of rolls.

15. A process for forming and working metals under pressure which comprises: passing a metal body through a metal working means supported in a chamber of uniform internal diameter having a closed end and constructed to withstand high internal pressures; and then through at least one annular spacer-support disposed within said chamber at the closed end thereof and sup-

ported by said end; a medium in said chamber capable of transmitting hydraulic pressure at an entry portion of said chamber for subjecting the billet to hydrostatic forces on the entrance side of the metal working means and at an exit portion for receiving the extrusion; controlling the speed of the emergent metal by providing a small clearance between the spacer-support and the emergent metal so that fluid shear stresses can act to control the speed of the emergent metal, the metal body having a transverse surface subjected to fluid pressure on both sides of the metal working means, the hydraulic pressure at the entry side being higher than at the exit side.

16. A process according to claim **15** in which the metal-working means is a die.

17. A process according to claim **15** in which the chamber has a uniform diameter throughout its entire pressurized length, whereby said chamber is characterized by the absence of any transverse walls therein.

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