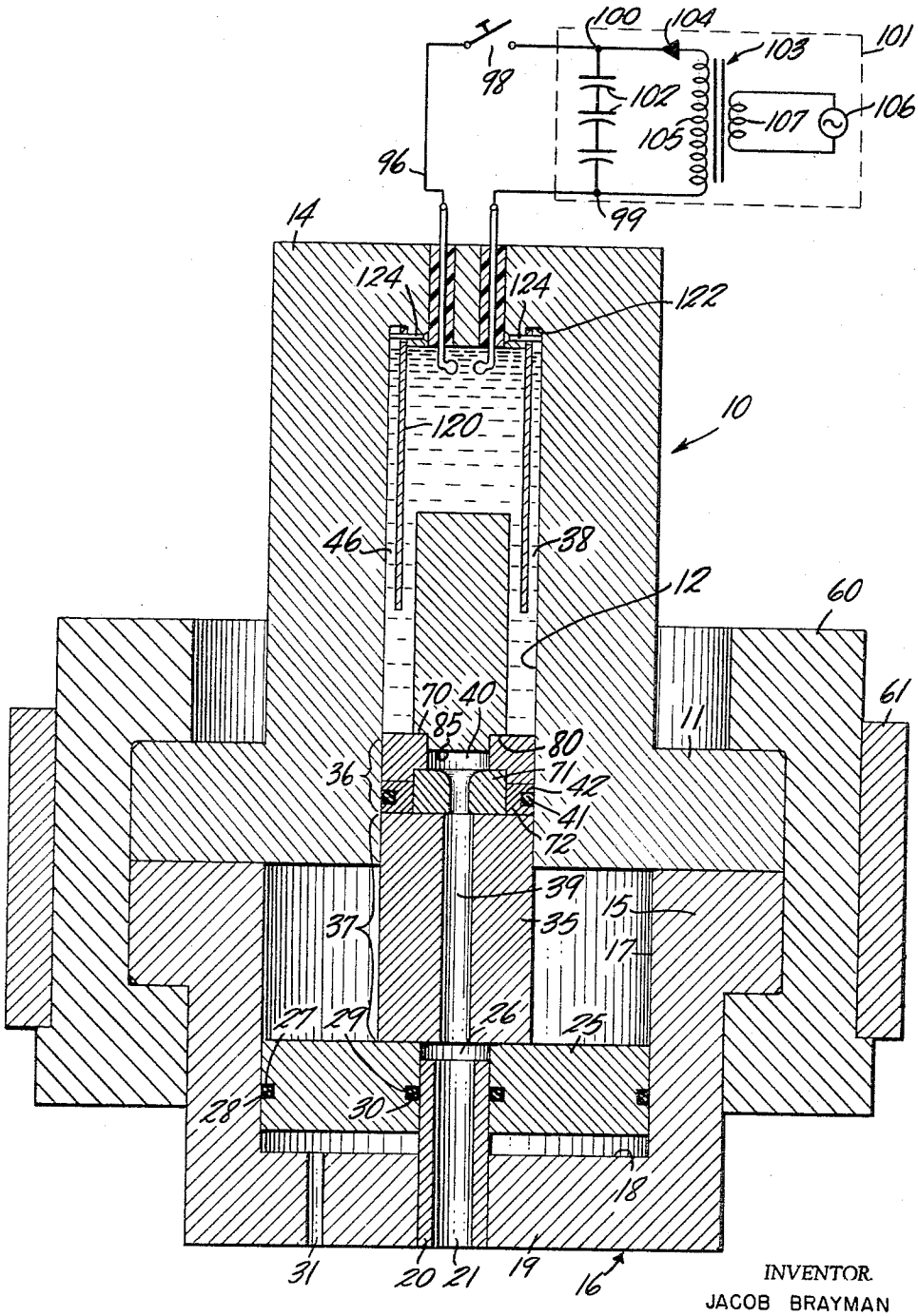
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CONTROL OF STRESSES DURING SHOCK-AIDED HYDROSTATIC EXTRUSION

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CONTROL OF STRESSES DURING SHOCK-AIDED HYDROSTATIC EXTRUSION

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This invention relates to hydrostatic extrusion techniques and, more particularly, to improvements in techniques which employ shock waves to initiate the extrusion of a billet of material using hydrostatic pressure.

A relatively recent development in the art of forming metal and other materials is to employ hydrostatic pressure to extrude the material through a die. In hydrostatic extrusion apparatus, a billet of the material to be extruded is disposed in a chamber with a portion of the billet pressed in areal contact with the perimeter of the die. A fluid is contained in the chamber surrounding the remainder of the billet, and when sufficiently high pressure to stress the billet into a plastic state is provided in the chamber, the billet is extruded through the die.

A problem encountered at one time in hydrostatic extrusion and a highly successful method of solving that problem are described in copending application Serial No. 236,602, now Patent No. 3,181,328, of Alexander Zeitlin entitled "Shock Aided Extrusion," filed November 9, 1962, and issued May 4, 1965. That patent is owned by the assignee of the present application. While reference may be had to the Zeitlin patent for a complete discussion of the problem and disclosure of a way of solving it, the problem and solution will be described briefly herein.

In extruding the billet, as previously stated, pressure is built up to a high enough value to stress the billet into its plastic state, and thereby facilitate its extrusion. Before the extrusion of the billet can begin, however, it is necessary to overcome the force due to static friction between the die and the billet. Accordingly, an excess of hydrostatic pressure, that is, a pressure somewhat higher than that required to extrude the billet, had to be built up in the chamber of hydrostatic extrusion devices prior to the development of the Zeitlin technique, namely, a pressure sufficient to not only stress the billet material but to overcome the static friction between the billet and the die. Once the pressure had been built up to the predetermined excess, the billet started to extrude. Immediately upon starting to extrude, the frictional resistance to extrusion is reduced to only a fraction of the initial static frictional resistance. The energy supplied by the excess hydrostatic pressure was then quickly converted into dynamic force exerted on the billet, and this created several difficulties during the period of time in which the excess energy was being dissipated, that is, the period of time until the pressure in the hydrostatic chamber was reduced to a level at which extrusion could take place at a normal rate.

To overcome this problem, the expedient disclosed in the Zeitlin patent referred to above is to create a shock wave in the chamber and impinging on the billet to provide the energy to overcome the static friction. More particularly, the pressure on the billet required for initiating extrusion is provided by a momentary shock pressure of sufficient amplitude that the hydrostatic pressure and the shock wave pressure together overcome the static friction, the shock pressure being of short enough duration that the amount of energy stored in response thereto by the billet extrusion system is smaller than the amount of energy which would have been so stored if the build-up of the break-through pressure had been developed solely by the primary hydrostatic pressure. Because the amount of stored energy is diminished, less such energy is available for conversion into dynamic force on the billet, and, accordingly, the billet is not violently accelerated immediately after break-through has occurred, as was the case prior to the development of the technique disclosed in the Zeitlin patent referred to above.

The shock pressure may be provided in various ways, such as by an explosive charge, by a transient electric charge in a body of pressurized fluid which directly or indirectly develops the pressure on the billet, or by exploding a thin wire by passing a high energy burst of electric current through the wire. By these and other devices, a pressure shock wave of short duration, say a few microseconds or of longer durations as may be required in particular situations such as for a particular billet material, normal extrusion pressure and other variable factors, is provided. The use of the energy of a short duration shock wave enables the pressure of the hydrostatic medium in the billet chamber to be maintained at the level which will sustain the extrusion of the billet once break-through has occurred.

A difficulty encountered in the use of shock wave pressure to initiate extrusion of the billet is that the shock wave propagates outwardly from the electrodes or other generating means in all directions; that is, it not only impinges upon the billet and initiates the extrusion but also propagates outwardly against the chamber wall. For example, in hydrostatic extrusion employing a hydrostatic pressure of about 200,000 p.s.i., an electrical discharge in the chamber may cause a pressure peak after a time of a few milliseconds of, say 400,000 p.s.i. This peak pressure, of course, acts upon the walls of the pressure vessel and creates very high stresses in those walls. Moreover, repeated use of the extrusion device and the consequent repetition of the high shock-induced stresses may bring about fatigue failure of the vessel in a relatively short time.

In accordance with the present invention, apparatus is provided for extruding an object including means defining a container for the object including closed walls and a top die at one end of the container. Means are also provided to subject the object to a pressure sufficient to produce extrusion thereof from the container through the die once the extrusion has been initiated. A shock pressure generator responsive to actuation thereof to subject the object to a shock wave of pressure supplementing the first named pressure and acting in conjunction therewith to initate the extrusion of the object is also provided. In order to significantly reduce or nearly eliminate the effects of the shock wave pressure on the container walls, a hollow member is spaced from the walls and positioned between them and the shock pressure generator. The member is designed to be extendable outwardly by the shock wave of pressure for absorbing at least a portion of the energy of the shock wave of pressure thus reducing the amount of energy acting on the walls of the container. In this way, the hydrostatic pressure in the chamber, which may be, say 200,000 to 300,000 p.s.i., does not generate any tensile stress in the liner, inasmuch as the pressure acts equally on both of its major surfaces.

The shock wave created by the generating means pro-

pagates in all directions and, moreover, travels in straight lines. Accordingly, the shock wave pressure impinges upon the inner surface of the liner. Tensile stresses are induced in the liner and cause it to be expanded outwardly. The expansion absorbs a considerable amount of the energy of the shock wave, energy which would otherwise be exerted upon the vessel walls. Inasmuch as the liner is subjected only to stresses created by the shock-wave pressure and not to stresses generated by the hydrostatic pressure in the vessel, the stresses in the liner will not be overly large, as are those in the vessel walls when a liner is not used.

The liner may be made of almost any material, but preferably, the material should have a high modulus of resilience; that is, it should be a high-strength, ductile material. Further, the liner may be designed to be reusable by utilizing only its elastic stress range in absorbing the shock wave energy. Generally, because of the high shock wave pressures created, the liner is prevented from being stressed beyond its elastic limit by limiting the degree of expansion by the shock wave pressure to that which prevents a strain beyond that at the elastic limit of the material. The limitation of expansion is best accomplished by spacing the liner from the vessel wall a predetermined distance such that it will bear against the wall upon being stressed almost to the elastic limit. When thus limited, the expansion may not fully absorb the energy of the shock wave, and a portion of the energy will act upon the vessel. However, as much as 75% or more of the shock wave energy will be dissipated by the elastic expansion of the liner. Limiting the stressing of the liner to stresses below the elastic limit has the advantage of enabling repeated operations of the hydrostatic extrusion device without replacement of the liner, thereby contributing significantly to the efficiency obtainable in commercial utilization of the device and reducing the costs. Nevertheless, the liner may also be designed to undergo higher stresses, thereby providing somewhat greater energy dissipation. A liner which is permanently deformed will be replaced after one, or perhaps, two or three uses.

For a better understanding of the invention, reference may be made to the following description of an exemplary embodiment, taken in conjunction with the accompanying drawing, which is an elevational view in section taken generally along the axis of a hydrostatic extrusion device having a liner installed therein.

The structure of the illustrated hydrostatic extrusion device is substantially the same as that disclosed in the copending application Serial No. 107,836, now Patent No. 3,126,096, of Gerard et al., entitled "Hydrostatic Extrusion System" which was filed May 4, 1961, and issued March 24, 1964, and which is owned by the assignee of the present application. Except for the pressure shock generator and the liner, the components of that apparatus are disclosed in full in the mentioned application and, therefore, will be described herein more briefly.

Referring to the drawing, a pressure-containing vessel **10** has at its lower front end a flange **11** encircling a bore **12** formed in the vessel to be open at the lower end of the vessel, and to extend upwardly from that open end. The word "bore" is used herein as descriptive of the structure of the central hollow space of vessel **10** rather than as descriptive of its origin. Thus, the bore **12** need not be a hole formed by boring, but, instead, may be formed, say, by machining out the interior of a cast hollow vessel **10**.

The bore **12** extends upwardly only part way through vessel **10** so that the top **13** of the bore is closed off by an end portion **14** of vessel **10** which is integral with the rest of the vessel. If desired, however, the pressure containing vessel may be of a type in which the interior bore extends through the vessel from end to end thereof and in which the top of the bore is closed off by a removable end closure. Thus, for example, the bore **12** may be closed at its top by a closure means similar to one of those disclosed in United States Patent 3,063,594 issued November 13, 1962, in the name of Gerard et al.

The flange **11** of vessel **10** registers with a flange **15** disposed at the upper end of and forming an integral part of a piston housing **16**. Such housing contains hydraulic cylinder **17** co-axial with and of greater diameter than the bore **12**. As shown, the cylinder **17** extends upwardly in housing **15** towards bore **12** from a cylinder bottom **18** formed by an end portion **19** of the housing **16** integral with the rest of the housing. An adapter tube **20** with a hollow axial core **21** extends upwardly through the end portion **19** to project into cylinder **17** beyond the bottom **18** thereof.

Received with a sliding fit in cylinder **17** is an annular piston **25** having a central cylindrical hollow space **26** in which the adaptor tube **20** is in turn received with a sliding fit. The piston **25** has formed in the exterior circumference thereof an annular groove **27** in which there is an O ring **28** providing a pressure seal between the piston and the wall of cylinder **17**. In like manner, the piston **25** has formed in the interior circumference thereof an annular groove **29** in which there is an O ring **30** providing a pressure seal between the piston and the wall of tube **20**. A conduit **31** passing through the bottom portion **19** of housing **16** permits injection of pressurized hydraulic fluid into cylinder **17** behind piston **25**.

Mounted coaxially on piston **25** is a lesser diameter ram **35** comprised of a head **36** and a stem **37**. The ram extends upwardly from the piston to have the front end of the ram received with a sliding fit in the open end of the bore **12** of vessel **10**. The ram plugs such open end so that the ram forms together with the part of the bore inwards thereof a billet container **38**. Communicating with that chamber is a coaxial passageway **39** extending through the length of ram **35** from a lower junction with space **26** inside piston **25** to an upper orifice **40** by which the passageway opens into the lower end of chamber **38**. The chamber **38** is otherwise rendered pressure tight at its front end by an O ring **41** seated in an annular groove **42** formed in the head **36** of the ram, the ring **41** bearing against the circumferential wall of bore **12** to form a pressure seal.

The chamber **38** is shown in the drawing as containing (1) a lesser sized billet **45** having its lower end seated over orifice **40** in the head **36** of ram **35**, and (2) a volume of hydrostatic pressure transmitting medium **46** filling the interspace in chamber **38** between the billet and the wall surface of bore **12** which bounds chamber **38**. Thus, the medium **46** entirely surrounds the billet except at its front end where the billet is seated on the ram.

During an extrusion operation, the vessel **10** and the piston housing **16** are clamped together by a split ring clamp formed of two identical semi-circular halves **60** of which one appears in FIG. 1. To assure that the two halves of the clamp do not become separate, a safety ring **61** is placed around the clamp. The clamp and safety ring may be constructed in accordance with the teachings in the aforementioned U.S. Patent 3,063,594.

The head **36** of ram **35** is comprised of an upper annular primary die **70**, a lower annular secondary die **71**, and an annular die holder **72** disposed below die **70** and around die **71**. The elements **70–72** of the die assembly are fastened together and to the stem **37** of the ram **35** by conventional securing means (not shown) as, say, bolts. The secondary die **71** needs no particular securing means since such die is entirely constrained by the primary die **70**, the die holder **72** and the ram stem **37**. If desired, the die assembly need include only a single die instead of the two dies **70** and **71**.

The bottom face **80** of the billet **45** and the top face **81** of the primary die **70** are matched in contour to make flat contact with each other over an annular area disposed radially outward of the orifice **40**. This annular area of contact forms a seal which prevents hydraulic fluid **46** in

the interspace around the billet from leaking underneath the billet into orifice 40 and thence out passageway 39.

As shown, the billet 45 as formed at the front end thereof a cylindrical stub 85 which projects into the orifice 40. This stub serves both to center the billet in relation to the die assembly in the course of setting up the apparatus and to provide a leader into the die during the extrusion process.

As so far described, the apparatus is the same as that disclosed in the aforementioned patent No. 3,126,096. In addition, the apparatus includes a pressure shock generator which is described in Zeitlin Patent No. 3,181,328 referred to previously. As disclosed in that patent, a pair of ball electrodes 90, 91 are disposed in the vessel 10 in the space at the top of bore 12 to be immersed in the fluid 46 filling the bore. The electrodes 90 and 91 are each mounted on a respective one of a pair of conductor rods 92, 93 which pass upwardly through and project from the top of vessel 10 by virtue of passing through respective ones of a pair of insulating liners or bushings 94, 95 tightly received in separate auxiliary bores extending through the top of the vessel to the main bore 12. Exteriorly of vessel 10 the rods 92 and 93 are connected through respective leads 96, 97 and a switch 98 in lead 96 to the terminals 99, 100 of a high voltage pulse generator 101. The generator 101, as shown schematically, comprises (a) large size capacitors 102 serially connected across the mentioned terminals, (b) a voltage step up transformer 103, (c) a rectifier 104 connecting the secondary winding 105 of transformer 103 in circuit with the serially connected capacitors 102, and (d) an A.C. power supply 106 connected to excite the primary winding 107 of the transformer.

The above-described apparatus is set up for cold extrusion in the following manner. With the safety ring 61, the split ring clamp 56 and the vessel 10 being removed from the housing 16, with the piston 25 being at the bottom of the hydraulic cylinder 17, and with the ram 35 upstanding from the piston as shown, a billet 45 of material to be extruded is seated in centered relation on the ram 35. The vessel 10 is then placed over the housing 15 so that the flange 11 of the vessel and the flange 15 of the housing are in registration, and so that the ram and the billet thereon slip into the bore 12 of the vessel. Next, the ring clamp is assembled to lock together the flanges 11, 15 and the safety ring 61 is placed around the assembled ring clamp. Finally, the chamber 38 within bore 12 is filled with hydraulic fluid in some suitable manner as, say, in the manner described in the mentioned Gerard et al. application Serial No. 107,836 or by injecting hydraulic fluid into bore 12 through passages 21 and 39. The apparatus is now ready to operate.

The extrusion operation is initiated by injecting hydraulic fluid through conduit 31 into cylinder 17 behind piston 25 so as to drive the piston upwardly. The pressure of the fluid injected behind the piston may be of the same order as that commonly used in the present day hydraulic art, i.e., between 10,000 p.s.i. and 50,000 p.s.i. In the view, however, that the face area of piston 25 is greater by, say, tenfold than the face area of ram 35, the driving pressure behind the piston is converted by a pressure multiplying action into a much high pressure exerted by the front of the ram 35 on the fluid 46 in the chamber 38.

As the ram 35 is driven by piston 25 into the bore 12, the ram automatically compacts the fluid 46 to build up the hydrostatic pressure therein to the level required to provide extrusion of the billet after it has been started. During this buildup of hydrostatic pressure, the forward movement of the ram lifts the billet so that the top thereof moves towards the vessel top 14. Sufficient clearance is however, provided between the top of the billet and the vessel top so that the required hydrostatic pressure is reached well before the top of the billet strikes the vessel top. Thus, it will be seen that the ram does not at any time exert any direct pressure on the billet.

Prior to the operative movement of ram 35 into the bore 12, the capacitors 102 have been charged so as to develop a high voltage across the terminals 99, 100 of the voltage pulse generator 101. Simultaneously with the building up of the pressure in fluid 46 to the required level to sustain the extruding of the billet once it has begun by the advancement of the ram into the bore, the switch 98 is closed in a timed manner to produce a high energy spark discharge of capacitors 102 through the gap between ball electrodes 90 and 91. That discharge acts upon the fluid 46 in which the ball electrodes are immersed to produce therein a pressure shock wave supplementing the ram-developed pressure and of an amplitude at least sufficient to bring the total pressure on the billet momentarily to a level sufficient to overcome static freetron and to thereby initiate the extrusion of the billet.

One billet extrusion has begun, the friction force opposing the extrusion drops radically, and the pressure necessary to keep the billet extruding drops commensurately to a pressure substantially the same as that initially generated by the ram. Hence, even though the shock wave quickly dies away, the extruding of the billet can be and is continued by continuing the advance of the ram 35 into the bore 12 without making any greater demand on the ram than to maintain the pressure on the billet the same as or less than the pressure initially built up on the billet by the ram.

Because the employment of the described pressure shock technique permits billet extrusion to be carried out by a primary drive pressure of lesser value than the pressure needed for breakthrough, the technique permits the use of a source of primary drive pressure (e.g., ram 35 and its hydraulic cylinder and piston drive unit) which is of lighter construction than what would be required by safety considerations if that source alone has to supply the breakthrough level of pressure on the billet.

While the amplitude of the shock wave is, as desired, sufficient (along with the ram developed pressure) to initiate extrusion of the billet, the duration of the shock wave is short, as say, on the order of from microseconds to milliseconds. During the short time interval over which the wave acts, the gross mass of the components of the billet extruding system in which energy is stored by deformation cannot be accelerated by the shock wave at a rate sufficient to produce an energy-storing deformation of those components commensurate in magnitude with the amplitude of the shock pressure. Hence, the total energy stored in the billet-extrusion system by a shock wave used to raise the pressure to that required to initiate extrusion is much less than the total energy stored in the system when the primary drive pressure is used for this purpose. It follows that after breakthrough occurs there is much less stored potential energy available to accelerate the billet. Therefore, the extruding billet is not subject to an initial violent acceleration and to the likelihood of separation of the front part of the billet from its tail.

In connection with the described shock-aided extrusion of a billet, it should be noted that the pressure shock wave acts on the components of the billet extrusion system and particularly upon the fluid 46 in a manner different from the primary drive pressure from the ram 35. That is, the shock pressure is propagated as a true wave of pressure through the body of fluid 46 and the rest of the system rather than being effective (as is the primary drive pressure) to produce a dimensional change in such body. While the amplitude of the shock pressure wave rises and falls like any other wave, the shock wave is preferably damped out within its first half period so that the wave is unidirectionally acting rather than alternating in character.

A significant portion of the total energy of the pressure

shock wave created by the shock wave generator acts upon the billet, but inasmuch as the pressure wave propagates in all directions with respect to the generator, the remaining portion of the energy acts on the bore **12** of the pressure vessel **10**. Moreover, the pressure created by the shock wave may be of very high magnitude, although of short duration, and may create extremely high stresses in the vessel **10**.

In accordance with the present invention, means are provided in the vessel **10** for dissipating the shock wave and preventing it from acting on the side walls thereof. More particularly, the energy of the pressure wave not utilized to initiate extrusion of the billet, that is, the excess energy, is absorbed by a liner **120** disposed between the bore **12** of the vessel **10** and the electrodes **92** and **93**, or other shock wave generators. The liner **120** is a generally cylindrical hollow member and is disposed in the vessel so as to lie generally concentrically to the bore **12**. Its upper end is received in a groove **122**, formed in the upper wall of the vessel **10** and having its outward surface contiguous to the bore **12**, and is held in place in that groove by a suitable means such as pins or screws **124** installed in holes extending radially outwardly from the openings in the top **14** of the vessel **10** in which the electrode sealing elements **94** and **95** are located. The outer wall of the liner **120** is spaced from the bore **12**, and therefore, the pressure of the fluid **46** in the vessel **10** acts upon both the inner and outer walls of the liner **120**. Accordingly, the liner is not subjected to any force, and consequent stress, due to hydrostatic pressure in the vessel.

The propagation of the shock waves from the pressure generator occurs along straight lines, and the shock will not follow a torturous path or change direction. Therefore, the lower end of liner **120** may be defined by straight lines emanating from the shock wave generator and passing through the upper corner of the billet **45**. Nevertheless, the liner **120** may extend lengthwise of the bore to a greater extent to enable the use of the hydrostatic device for billets of smaller sizes, but the position of the lower end of the liner **120** is limited by the top-most position of the top of the die element **36** as it is driven upwardly by the ram **37**.

The liner **120** may be made of almost any high-strength, ductile material having a high modulus of resilience, that is, an ability to absorb energy up to the elastic limit, or a high modulus of toughness, that is, an ability to absorb energy up to fracture. The shock-wave pressure acts on the inner wall of the liner **120**, thereby subjecting it to tensile stresses in the circumferential direction. A significant portion or all of the excess energy of the shock wave is thus utilized in straining the liner, that is, in expanding it outwardly. Thus, materials having the properties specified above are preferred.

The liner **120** can be designed and installed in the vessel so as to be stressed only to a degree which is within the elastic limit of the material, and accordingly, after cessation of the stress generated by the shock-wave pressure, it will elastically return to its unstressed dimensional form. More particularly, the stresses generated in the liner may be limited by spacing the liner close to the bore **12** such that it will come into contact with the bore when it is expanded outwardly to an extent that it is strained to a point slightly below the elastic limit. Further strain, other than that corresponding to any additional strain in the walls of the vessel **10**, is therefore prevented. While the shock-wave energy acting on the inner wall of the liner is thus transferred to the vessel **10**, the major portion of the excess energy of the shock wave has already been absorbed in expanding the liner and will have only a minor affect upon the vessel.

While it will generally be necessary to limit the stress in the liner in the manner described above to stay within the elastic range of the material, a liner made of a very high strength material used in an extruding operation requiring a relatively low energy shock wave to initiate extrusion may be designed to operate within the elastic range without having its expansion limited by contact against the vessel bore **12**. The liner may also be designed and installed so that it is stressed into the plastic range. In such a case a new liner is then employed for each extruding operation, or perhaps for each two or three operations. Inasmuch as a new billet must, of course, be positioned in the chamber after the previous billet has been extruded, the replacement of the liner **120** may be accomplished with little difficulty or interruption in the use of the device. Other means of installing the liner **120** in the vessel **10** may be employed to facilitate its replacement. For example, a detent arrangement on the inner surface of the upper end might be utilized so that the liner is sufficiently secured for a single use and a new liner can merely be pressed into place in the slot **122** after removal of the old one.

The above described embodiment of the invention is merely exemplary, and many variations and modifications will be apparent to those skilled in the art and may be made without departing from the spirit and scope of the invention. All such variations and modifications are intended to be included within the scope of the invention as defined in the appended claims.

I claim:

1. Apparatus for extruding an object comprising, means defining a container for said object which includes closed walls and a top die means at one end of said container means, means to subject said object to a pressure sufficient to produce extrusion thereof from said container means through said die means once said extrusion has been initiated, a shock pressure generator responsive to actuation thereof to subject said object to a shock-wave of pressure supplementing said first named pressure and acting in conjunction therewith to initiate said extrusion of said object, and means including a member positioned between said closed walls of said container means and said generator and deflectable by the shock-wave of pressure for absorbing at least a portion of the energy of said shock-wave of pressure and reducing the amount of energy acting on the walls of said container means.

2. Apparatus for extruding an object comprising, means defining a container for said object which includes closed walls and a top die means at one end of said container means, means to subject said object to a pressure sufficient to produce extrusion thereof from said container means through said die means once said extrusion has been initiated, a shock pressure generator responsive to actuation thereof to subject said object to a shock-wave of pressure supplementing said first named pressure and acting in conjunction therewith to initiate said extrusion of said object, and means including a hollow member spaced from and positioned between said closed walls of said container means and said generator and expandable outwardly by the shock-wave of pressure for absorbing at least a portion of the energy of said shock-wave of pressure and reducing the amount of energy acting on the walls of said container means.

3. Apparatus according to claim **2**, wherein said hollow member is spaced from the walls of said container means such that it contacts the walls of the vessel upon being stressed to a point within the elastic limit of the material from which it is formed.

4. Apparatus for hydrostatically extruding a billet comprising, container means providing a chamber for containing both a billet and a volume of hydraulic fluid disposed between said billet and the chamber-bounding wall of said container means, die means at one end of said chamber, means adapted by pressurizing said hydraulic fluid to subject said billet to a pressure sufficient to produce extrusion thereof from said chamber through said die means once said extrusion has been initiated, a shock pressure generator responsive to actuation thereof to subject said billet to a shock-wave pressure supplementing

said first named pressure and adapted in conjunction therewith to initiate said extrusion of said billet, and a hollow liner disposed in spaced relation to said chamber-bounding wall of said container means and surrounding said shock pressure generator, said liner arranged in said chamber to receive the portion of said shock-wave of pressure not propagated onto said billet and expandable outwardly thereby to absorb at least a portion of the energy thereof.

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