This invention relates to apparatus and methods for explosive forming. In particular, this invention relates to apparatus and methods for deforming a blank into the cavity of a die by setting off an explosive charge in proximity to the blank. In the past, the forming of parts from a single blank or sheet of material into various configurations was accomplished generally by purely mechanical devices. One such mechanical device which has been quite popular is the stamp press or drop hammer which employed a large mass moving in a rapid motion to drive the blank into a die. However, the mechanical devices are bulky machines which are very expensive and must be permanently installed. Furthermore, the use of these devices to produce parts in a complex configuration from a single blank required a multiplicity of dies and/or forming operations if the part could be mechanically formed to the configuration at all.

Accordingly, industry has cast about to find other methods and apparatus for forming parts from a blank. One forming operation that has received considerable attention from industry utilizes the blast from an exploding charge to force the blank into the die. If this forming is accomplished by exploding the charge in the air near the blank, damage to the blank and excessive heating thereof often results. Furthermore, forming by air explosion is a relatively inefficient process unless a container for the explosion is provided, such container preferably being closed and sealed to retain the powder gases therein.

Several methods and apparatus have been suggested to alleviate the blank heating and damage problems and to increase the efficiency by exploding incompressible or non-compressible material such as water. Then by means of the incompressible material, the explosive forces are transmitted directly to the blank surface thus accomplishing the forming operation. Unfortunately, the dynamic action of the shock wave transmitted by the incompressible medium and the inertial and structural restraint of the blank combine so that the blank is deformed in a generally parabolic shape. Thus the center of the blank hits the bottom of the die first thereby trapping air between the sides of the die and the deforming blank. This trapped air not only prevents complete forming of the part to the die configuration but reacts in an adiabatic manner to release sufficient heat to damage the part and possibly even the die. Evacuation of the die cavity has partially alleviated this problem.

However, the most desirable manner of evacuating the die is to connect a port to the lowest point of the cavity and then to pull as efficient a vacuum as possible on the port. The disadvantage of this arrangement especially in forming dome-shaped objects is that the parabolic deflection of the blank will bottom against the port and prevent a pocket or pockets of air from escaping. The air so trapped, of course, will prevent complete forming in conformance with the die. Accordingly, the present invention provides a method and apparatus for controlling the explosive deformation of a blank in a forming operation. More particularly, this invention provides a method and apparatus for controlling the distribution of the forces acting upon a stock blank as a result of the exploding of a charge in a relatively incompressible medium by interposing a generally compressible gaseous material between the blank and the incompressible medium. By use of this interposed gas, the forces acting upon the blank are controlled so as to produce a relatively smooth radially inward movement of the blank thus permitting the blank to progressively form into the cavity of the die. For dies having an evacuation port in the lower portion of the cavity thereof, this invention is particularly useful in that the progressive forming will actually aid in the evacuation of any residual gases or matter from the die cavity.

In addition, the present invention can be modified to control the pressure of the interposed gas whereby the shock front can be closely controlled to provide a variety of force patterns acting upon the blank. It is to be understood that the terms blank and stock-blank are used interchangeably herein.

The drawing illustrates an apparatus which can be used in accordance with the present invention. A container 10 and die 11 are oriented so that a blank 12 is retained therebetween. Blank 12 is simply a sheet of material which is to be formed and could be of any material or in any configuration. For forming domes, it has been found to be convenient to use a circular sheet of material for blank 12. Container 10 holds a substantially incompressible medium 14 which for many applications could simply be water. However, other liquids such as barite or galena weighted oil well drilling mud, heavy or more compressible liquids, and even solids such as talc have been employed with varying degrees of success for medium 14. An explosive charge 16 is suspended in medium 14 so as to be spatially displaced from blank 12.

In the apparatus shown in the drawing, a flexible diaphragm 17 is arranged so as to interpose a gas or relatively compressible material between medium 14 and blank 12 in the area or volume indicated generally at 18. Diaphragm 17 is sealed to a blank holder 20 which can be used to mechanically retain blank 12 against die 11. Blank holder 20 acts as a brake during the forming operation to prevent circumferential buckling or wrinkling due to "over flow" or the inertia of the moving blank. That is to say, buckling or wrinkling of blank 12 particularly at the edges thereof can be reduced by employing blank holder 20.

Blank holder 21 is arranged so as to interpose the gas column 19 into the area of blank 12. A port 22 is connected into space 18 through blank holder 20. By connecting a means for supplying and withdrawing gas to port 22, the pressure in space 18 can be controlled which in turn provides a means of controlling diaphragm 17 so that it can be caused to assume a flat, concave or convex configuration before charge 16 is exploded. Reversible, variable delivery pump 23 and valve 28 are shown as a typical arrangement for providing the means of controlling the orientation of diaphragm 17.

In the drawing, die 11 is shown as having a removable upper portion or draw-die 24 which defines the upper portion of cavity 26. The main reason for this arrangement is so that the initial bending radius for cavity 26 can be varied simply by replacing draw-die 24 with another draw-die that will mate with the lower portion of die 11. It is to be understood that die 11 could be made in one piece if desired and the configuration of cavity 26 as well as the position and/or number of exhaust ports are dependent only upon the desired configuration of the finished part.

As mentioned hereinbefore, it has been found to be advantageous to evacuate the cavity 26 so as to produce a substantial vacuum therein during the forming operation. Accordingly, cavity 26 is connected to a vacuum.
inducing means such as pump 29 by means of port 27.  

Next consider the actual accomplishment of a forming operation in accordance with the present invention. In particular, consider that a charge 16 is suspended in place as shown in the drawing in the cavity of tank 14. Also assume that tank 14 has been charged with a quantity of gas via port 22 after which port 22 is sealed by a check valve or other means so that no gas can escape from space 18. Diaphragm 17 in some actually performed tests was simply a polyethylene membrane having a thickness of about .001 inch. Although this invention is obviously not limited to either of these specific examples.  

After charge 16 is exploded, the shock-front created thereby will compress the gas in space 18 which will start the deformation of stock-blank 12 by a relatively uniform force distribution across the surface thereof. Thus as stock-blank 12 begins to move into cavity 26, it will be forced against the bending radius and sides of draw die 24 with approximately the same force as that causing the downward movement. The stock-blank 12 will thereby be caused to conform to the sides and thence to the bottom of cavity 26 by a relatively smooth, progressive flow-type of deformation without prematurely sealing exhaust port 27.  

It has been found that excellent results can be obtained by maintaining the gas pressure in space 18 so that diaphragm 17 assumes the general shape of a concave bulge into medium 14 at the time charge 16 is exploded as is shown generally in the drawing. It is believed that the concave bulge of the gas in space 18 refractions the flat or convex shock wave advancing downward from the explosion into a more concave front which reacts against stock-blank 12. This increases the force acting at the sides of blank 12 as it deforms and improves the flow distribution in the parts.  

Although obviously all that occurs after the explosion of charge 16 is not rigorously known, some pertinent observations can be made. For instance, it is believed that progressive compression of the gas converts a portion of the applied shock to potential energy for delayed and more sustained work. Further, it is believed that a slower and more uniform acceleration of the blank is produced which lowers the differential particle velocity and materially reduces excessive thinning and fracture hazards. Since relatively compressible gases such as air have less viscosity and mass than incompressible materials such as water, the forward force of the air cushion is more easily and uniformly directed normal to the rapidly changing surface of the part during forming. This produces lateral forming superior to that of any previously known explosive forming apparatus or processes. That is to say, the separation of the medium from the blank with a resilient cushion produces an increased development and release of useful afterflow energy from the medium entering the cushion area and the die cavity.  

It should be noted that the diaphragm 17 need not be designed to stretch into cavity 26. In fact, it has been found to be satisfactory to allow diaphragm 17 to rupture after it has deflected towards cavity 26. A cavitation effect is thus produced as the gas in space 18 will form a multitude of bubbles which collapse from the extreme compression thereby creating cavitation forces which hammer blank 12 to the shape forming surfaces of die 11.  

There are many variations of the materials that can be used for the present invention. The diaphragm 17 could be polyethylene or aluminum foil or stainless steel sheeting or copper or a charge of wide variety of materials as long as the amount of energy absorbed by the diaphragm is compatible with the forming operation. In fact, diaphragm 17 could be omitted entirely and blank 12 and die 11 placed over container 10 in an inverted arrangement from that shown in the drawing. By such an arrangement space 18 containing the gas could be controlled entirely by the amount of incompressible medium 14 that is used. In an arrangement in accordance with the structure actually shown in the drawing, the top of container 10 could include a "blow-out" plate as shown or it could be left open to the atmosphere of explosives available for charge 16. For instance, the deflagrating or "low" explosive materials such as smokeless powder or black powder could be used, these type explosives generally having a burning rate along a column in an order of hundreds of feet per second dependent upon the degree of confinement. However, caution should be observed in utilizing the nitrocellulose-type powders because slightly excessive amounts of the charge can produce a "high-order" reaction with detonation causing bomb-like results.  

Detonating or "high" explosives such as dynamite, TNT, RDX (primacord) or PETN are characterized by a reaction zone traveling through the charge at velocities of thousands of feet per second. Because of the speed of reaction, complete in only a few milliseconds of a second, a detonating type explosive releases its energy at a constant rate regardless of confinement. When a high explosive is detonated, a shock wave is generated in the containing medium with the initial velocity of thousands of feet per second which generates an initial pressure of several million p.s.i., followed by a gross expansion of the medium away from the detonation center (afterflow). Accordingly, "high" explosives are generally preferred for explosive forming since confinement with the use of heavy, expensive clamping equipment is not required and the container can be designed for multiple re-use. Also there are known techniques for shaping a high explosive charge to control the magnitude and direction of detonation force. Clearly these techniques could be advantageously utilized within the spirit of this invention. Therefore, control of the explosive pressure forming distribution can be achieved by varying the mass distribution and/or shaping of the explosive charge as well as by varying the distance between the point of explosion and the blank (commonly referred to as "standoff").  

Many variations of the method and apparatus disclosed by this invention will be readily apparent to one having normal skill in the art without departing from the spirit of this invention. For instance, the die 11, gas-filled space 18 and blank 12 could be immersed in a pit containing the incompressible medium in which a charge is exploded thereby providing a readily adaptable "container" for medium 14. Also space 18 could be provided simply by gluing or holding a gas filled bag against blank 12 thereby removing the need for blank holder 20. This would be especially useful for "bulging" or bulge-forming of large parts. If a large volume of gas is needed, a sleeve with diaphragm 17 sealed thereto could be added on top of hole 21 in blank holder 20.  

Those having normal skill in the art will appreciate the fact that there are a multitude of arrangements available for retaining the components shown in the drawing in proper position. By way of example, cables and clamps could be used to secure container 10 to blank holder 20 although it would probably be desirable in so doing to leave some pressure relieving arrangement such as the "blow out" plate in the top of container 10. Further, through-bolts or clamps could be employed to retain die 11 and blank holder 20 in position. However, it should be appreciated that the apparatus of the drawing could be successfully utilized as shown since the vacuum drawn on cavity 26 would ensure that blank 12 at the parts of die 11 would remain atmosphere and the weight of container 10 with medium 14 contained therein could be sufficient to maintain contact with holder 20 and diaphragm 17 for a sufficient length of time to allow the forming operation to be performed.
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5. An apparatus for explosively forming parts from a stock-blank comprising:
   a die having a cavity for forming said stock-blank;
   means for holding a stock-blank against said die;
   means for generating an explosive force;
   means for containing a substantially incompressible medium on the side of said stock-blank opposite said die;
   said incompressible medium being adapted to transmit the forces created by said explosive force generating means toward said stock-blank; and
   means for supplying gas under pressure between said stock-blank and said incompressible means for transmitting the explosive forces into forces acting substantially normally to the surface of said stock-blank during deformation thereof into said cavity of said die.

6. An apparatus for explosively forming parts from a stock-blank, as set forth in claim 5 further including:
   a flexible diaphragm between said containing means and said gas supplying means, said diaphragm being adapted to be supported by the pressure of said gas and extending concavely into said incompressible medium.

7. An apparatus for explosively forming parts from a stock-blank, as set forth in claim 5, further including:
   means for evacuating the cavity of said die.

8. An improved apparatus in accordance with claim 5 which includes means for selectively controlling the pressure of said gas between said stock-blank and said incompressible means.

References Cited by the Examiner

UNITED STATES PATENTS

2,935,038 5/1960 Chatten
3,044,430 7/1962 Zeigler
3,068,822 12/1962 Orr et al.

FOREIGN PATENTS

766,741 1/1957 Great Britain.

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