Nov. 27, 1962 G. N. RARDIN 3,065,720

APPARATUS AND METHOD FOR HIGH VELOCITY FORMING OF METALS USING HIGH EXPLOSIVES

Filed Oct. 8, 1957 4 Sheets-Sheet 1

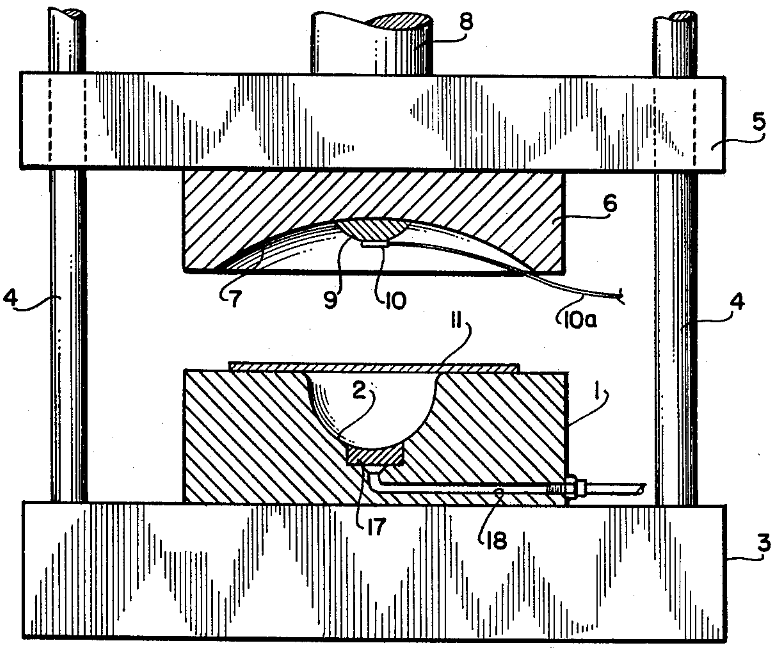

Fig. 1

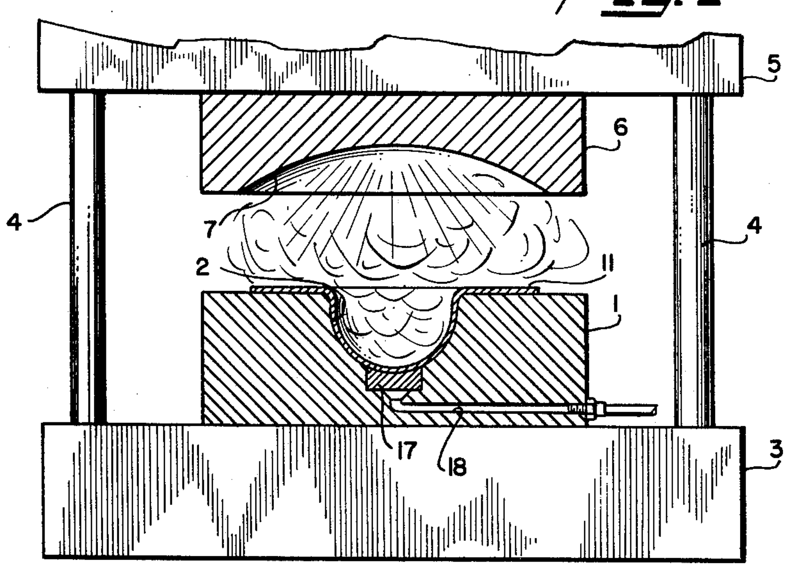

Fig. 2

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4 Sheets-Sheet 2

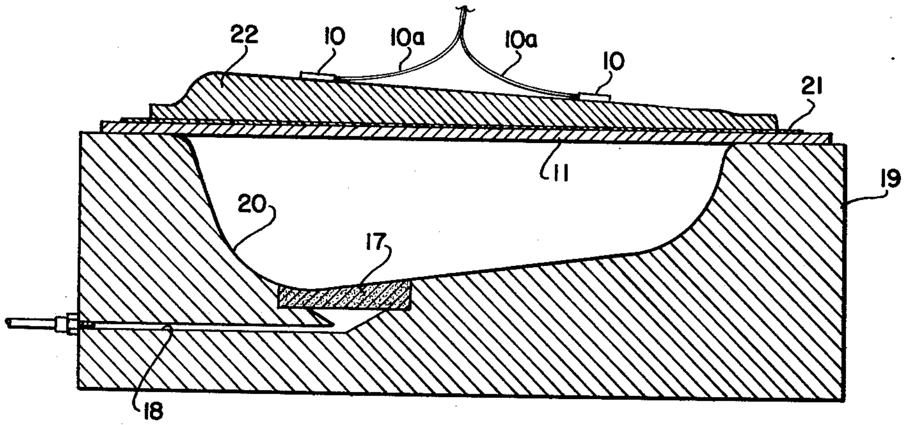

Fig. 3

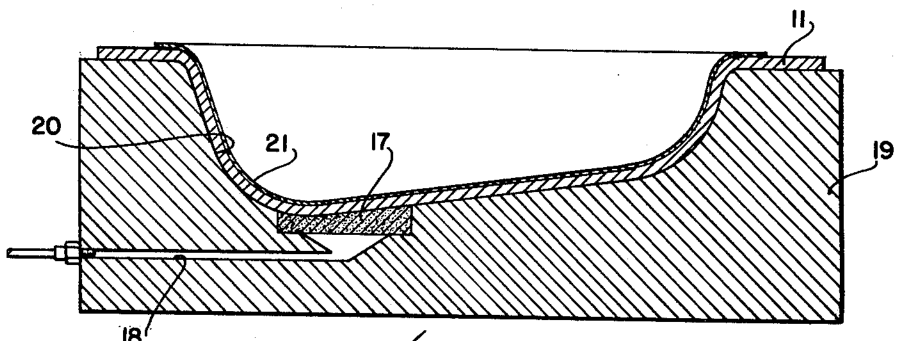

Fig. 4

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APPARATUS AND METHOD FOR HIGH VELOCITY FORMING OF METALS USING HIGH EXPLOSIVES

Filed Oct. 8, 1957 4 Sheets-Sheet 3

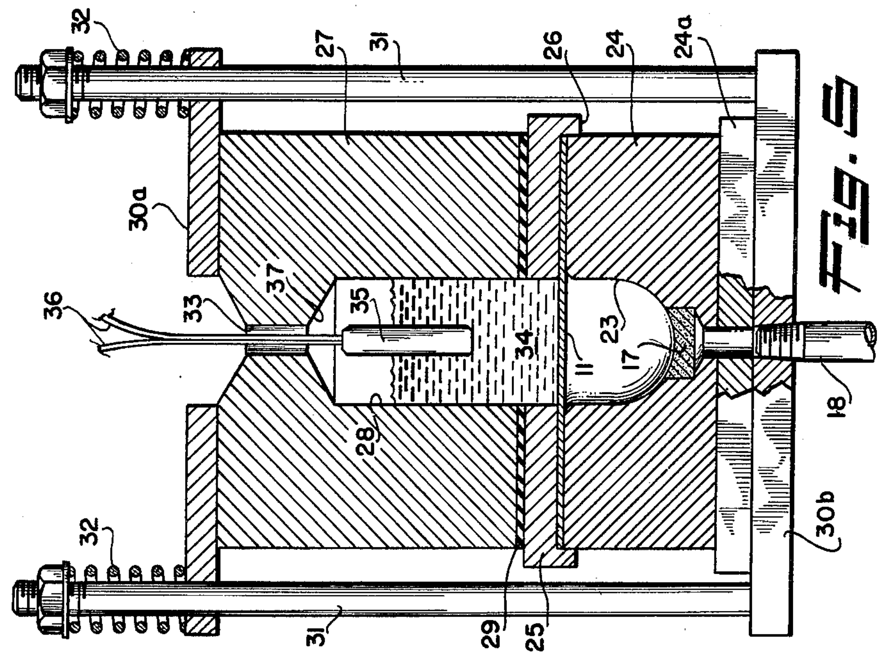

Fig. 5

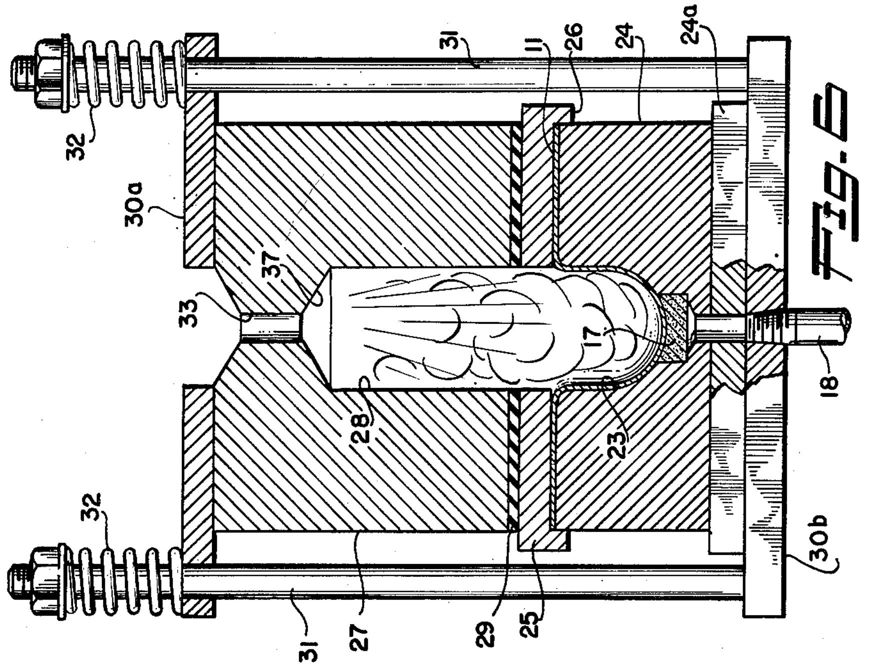

Fig. 6

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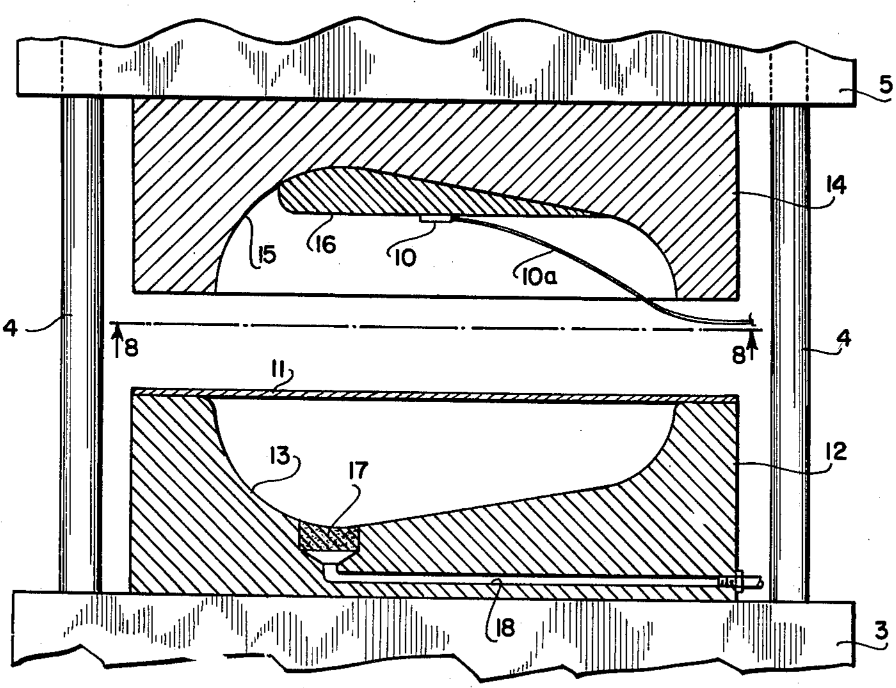

Fig. 7

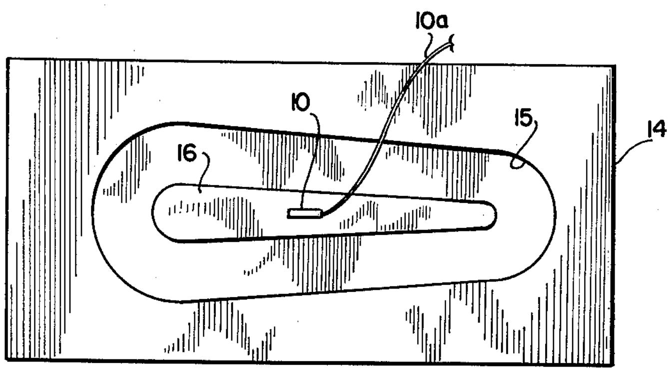

Fig. 8

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APPARATUS AND METHOD FOR HIGH VELOCITY FORMING OF METALS USING HIGH EXPLOSIVES

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5 Claims. (Cl. 113—44)

This invention relates to the forming of sheet and/or plate metals, and more particularly to a method and apparatus for forming high strength metals from sheet and/or plate forms by the use of high explosives.

The present day state of the forming art contains certain limitations on the types of materials upon which satisfactory forming operations can be performed. With high strength materials having high tensile strength, as exhibited by AISI type 302 Stainless Steel or 17–7 PH and AM–350 austenitic steels, or materials which become hardened during working, as exemplified by 6A1–4V titanium alloy, limitations are present in using such forming devices as the hydropress and the stretch form because of the inability of some of the forming devices to generate work forces greater than the tensile strength of some of the materials. Where the tensile strength of the material does not exceed the capacity of the forming device, the forming of high strength titanium and stainless steels require heavy equipment hard dies, in addition to elevated temperatures and expensive forming techniques wherein the material must be over-formed to compensate or allow for springback upon physical release of the formed material At best, many complex shapes cannot be made from these high strength materials because of poor ductility, low elongation and high yield strengths of the materials that is not surmountable by the forming devices.

Present day forming devices having capacities capable of forming some of the high strength materials are rather slow acting because of the size or cumbersomeness thereof, which in turn requires a continuous heavy force for load application continuously during the forming operation and thus setting up strains or stresses in the material capable of causing failure of the material due to cracking or tearing as the rate of forming and the resultant rate flow of the material is substantially below the rate of crack propagation of the material, which in stainless steel is approximately 15,000 ft. per second. By attaining forming velocities above this, the material is formed or forced into shape before the elastic limit of the material is reached.

Accordingly, it is an object of this invention to provide an apparatus and method for forming high strength metals without large and heavy forming device installations.

It is another object of this invention to provide an apparatus and method for forming high strength metals without having to anneal the material first prior to the application of the forming force.

It is a further object of this invention to provide an apparatus and method for the forming of metals that become hardened by working without having to be concerned about such work hardening during the forming operation.

It is still a further object of this invention to provide an apparatus and method for increasing the percentage of elongation attainable in forming operations on high strength metals.

A still further object of this invention is to provide an apparatus and method for forming high strength metals at a rate of forming in excess of the rate of crack propagation in such materials, thusly reducing forming scrappage.

It is a further object of this invention to provide an apparatus and method to eliminate measurable material springback in the forming of high strength metals.

Another object of this invention is to provide an apparatus and method for forming high strength metals to complex shapes heretofore unobtainable by prior methods and devices.

Other objects and advantages will become apparent from the following description taken in connection with the accompanying drawings in which:

FIGURE 1 is a partial cross-sectional view showing one embodiment of this invention prior to the forming operation;

FIGURE 2 is a partial cross-sectional view similar to FIGURE 1 and after completion of the forming operation;

FIGURE 3 is a cross-sectional view of a further embodiment of this invention prior to the forming operation;

FIGURE 4 is a cross-sectional view similar to FIGURE 3 after completion of the forming operation;

FIGURE 5 is a partial cross-sectional view of a still further embodiment of this invention prior to the forming operation;

FIGURE 6 is a partial cross-sectional view of the structure shown in FIGURE 5 upon completion of the forming operation;

FIGURE 7 is a partial cross-sectional view of a modification of the embodiment of the invention shown in FIGURES 3 and 4, showing this modification prior to the forming operation; and

FIGURE 8 is a view taken along lines 8—8 of FIGURE 7.

Generally stated, the invention is practiced by forming high strength metals through utilization of the dynamic forces from the shock wave and subsequent pressures of detonated high explosives having a high rate of detonation, and directing the shock waves and pressures against the metal to be formed in such a manner as to force it into a suitable die or container. Because of the high detonation rate of the high explosive resulting in high velocity shock waves, the directing or transmission of the shock waves against the material to be formed results in the material being formed before initiation of a fracture, which is time dependent. This, in turn, avoids material breakage caused by the forming stresses since the velocity of forming is above the crack propagation rate for that material.

Referring more particularly to the drawings, in FIGURE 1, a female forming die 1, having a contoured die cavity 2, is mounted on a bed or platen member 3 which has a plurality of guide shafts 4 extending vertically therefrom. A movable member or upper platen 5, having a plurality of openings therethrough to accommodate passage of the guide shafts 4, has secured thereto a reflector member 6 having a parabolic concave surface 7. The distance between die 1 and reflector 6 is adjustable by connecting member 8 extending from the upper surface of platen 5 to a linear actuating means, such as member 8 being a part of or connected to a hydraulic piston or engaging a mechanical drive such as gearing, thereby causing a vertical linear movement of reflector 6 and platen 5 along guide shafts 4, such movement being relative to die 1 and bed 3. It is to be understood that the reflector 6 may be stationary with the die 1 being movable.

Located on the concave surface 7 of reflector 6 is a high explosive charge 9 with a blasting cap 10 shown attached thereto; the explosive having a detonation rate of 4,000 meters or more per second as possessed by such explosives as tetryl, PETN (pentaerythrite tetranitrate, and RDX (Cyclonite). Electrical conductors

10a connect the blasting cap 10 to any suitable source of electrical energy for exploding the cap 10.

A sheet of high strength raw material or workpiece 11 on which a forming operation is to be performed is set on the upper surface of die 1 and covering the die cavity 2.

The workpiece 11 is formed by being forced into the die cavity 2 and assuming the contour or shape thereof, as indicated in FIGURE 2. The source of the forming force is the shock wave and subsequent pressures resulting from the explosive charge 9 being detonated by the blasting cap 10, with the upward pressures from the detonation being directed downward by surface 7 to the workpiece 11 and combining with the downward pressures from the detonation to cause that portion of the workpiece over the die cavity 2 to be forced into contact with the contoured wall of cavity 2. By using a high explosive having a detonation rate of 4,000 meters or more per second, the shock waves and pressures resulting from such detonation are of such velocity so as to cause the workpiece 11 to be formed at a velocity sufficiently fast that the workpiece is formed before the elastic limit of the material is reached resulting in a crack or failure of the material.

In order to allow the workpiece 11 to come into entire and complete contact with the surface of die cavity 2, the air between the surface of die cavity 2 and the workpiece 11 is removed therefrom through a passage 18 connected to any suitable vacuum pumping means (not shown). To provide continuity of the surface of die cavity 2, a porous insert 17 is placed in the surface of die cavity 2 adjacent the vacuum line passage.

The vertical distance between die 1 and reflector 6 may be varied depending upon the amount of explosive pressure force to be delivered to the workpiece, the type of explosive charge 9 that is used and the amount of the depth and/or area of the formed shape. For a given charge of a given explosive, a greater explosive forming force can be directed to the workpiece by lessening the vertical distance between the die and reflector; and vice-versa, a lesser explosive forming force will result by increasing the vertical distance. Should the dominate factor in the forming of a part be the precise distribution of the explosive forming forces, which is controlled by the shape of the reflector surface by directing or aiming the explosive pressures, the degree or level of the explosive forming forces can be changed by varying the amount of explosive charge or by substitution of explosives having a greater or less explosive pressure. The shape of the reflector surface will be dependent upon the configuration of the formed workpiece as the distribution of the upward explosive forces are controlled by the direction of downward aiming thereof by the reflector surface. Generally, the shape of the reflector surface is substantially similar and opposite to that of the forming die cavity, whether for a symmetrical type of forming die cavity as shown in FIGURES 1 and 2, or for an unsymmetrical or irregular shaped forming die cavity.

This latter shaped forming die cavity is exemplified in FIGURES 7 and 8 wherein female forming die 12 has an unsymmetrical surface forming die cavity 13 while reflector 14 has a reflecting surface 15 which is substantially antipodal or opposite of the surface forming die cavity 13. Also, the thickness, length and width of the explosive charge 16 is in direct proportional relationship with those dimensions of the die cavity. As can be seen in FIGURE 7, the thickest portion of the explosive charge 16 is located over the deepest portion of forming die cavity 13 while the thinnest portion of explosive charge 16 is located over the shallowest portion of forming die cavity 13. FIGURE 8 shows the relationship of the length and width of the explosive charge 16 to the length, width and depth of forming die cavity 13 wherein the longest portion of explosive charge 16 is over the longest portion of forming die cavity 13, the widest portion of explosive charge 16 is over the deepest and widest portion of forming die cavity 13, while the narrowest portion of explosive charge 16 is over the shallower and narrower portion of the forming die cavity 13.

Air in forming die cavity 13 is exhausted through porous insert 17 and vacuum line 18, as discussed above.

Should a total forming force be desired that is less than that obtained by the use of the reflector, the high explosive charge may be mounted right on the workpiece 11, as shown in FIGURE 3. Here, female forming die 19 has a die cavity 20 formed therein and porous member 17 connected to a vacuum to passage 18 and providing continuity of die cavity 20. The workpiece 11 is mounted on the top surface of die 19 with a sheet of insulation material 21 placed between workpiece 11 and a sheet form high explosive charge 22, with blasting caps 10 therewith. Insulation material 21 is used as a means for insulating the instantaneous high temperature from the high explosive charge detonation from the workpiece 11, and may be any suitable means that is flexible such as glass cloth, clay, putty, powder, etc. The same relation between the shape of the explosive charge 22 and forming die cavity 20 exists here as discussed above with FIGURE 7.

In order to accomplish total detonation of explosive charge 22 in a shorter time, an additional blasting cap 10 is used resulting in detonating waves or fronts emanating spherically from two points rather than one and thus providing faster total detonation consumption of explosive charge 22. It is to be understood that any number of blasting caps may be used in any pattern desired.

In this embodiment there is a larger downward explosive pressure force on workpiece 11 in view of explosive charge 22 being closer to workpiece 11 and forming die cavity 20, but the total explosive forces on workpiece 11 are less than those in FIGURES 1, 2 and 7 in that here the upward forces are lost completely rather than being reflected back to the surface of the surface of the workpiece by a reflector.

FIGURE 5 shows another embodiment of this invention in which a uniform pressure can be transmitted to the entire area of the workpiece in the forming die cavity 23 in die 24. A clamping ring 25 having a circumferential rim 26 is placed over the workpiece 11, holding such in place with forming die 24 by the rim 26 peripherally surrounding die 24. An enclosure member 27 containing an explosive chamber 28 is moutned on ring 25 with a sealing gasket 29 therebetween. The forming die 24 and its base 24a, workpiece 11, ring 25, gasket 29 and enclosure member 27 are clamped together in an assembled relation by pressure plates 30a and 30b which are biased together by tie-rods 31 and springs 32. Explosion chamber 28 is open to the atmosphere through passage 33 extending through the top of enclosure member 27. A non-compressible medium 34, shown here as a liquid, is placed inside of chamber 28 along with an explosive charge 35 connected to a suitable electrical energy ignition means by conductors 36. Explosion chamber 28 does not necessarily have to be filled completely with non-compressible medium 34, the only requirement being that there is sufficient medium to protect the workpiece 11 against heat or debris from the explosive charge 35 in addition to covering the complete area of workpiece 11 exposed to the explosion chamber for uniform transmission of the explosive forming forces generated by the explosive charge 35 being detonated in the explosion chamber 28. Note that the top of the explosion chamber 28 is tapered or dome-shaped as indicated at 37, which assists in directing some of the upward explosion forces downward to react upon medium 34. Explosion chamber 28 is open to the atmosphere through passage 33 at all times to permit some loss of pressure caused by detonation of explosive charge 35; otherwise the pressures generated by detonation of explosive charge would be more than explosion chamber 28 could contain as 1 cubic centimeter of PETN detonated in a completely enclosed chamber generates approximately 3,780,000 pounds pressure.

In order to accomplish the withdrawal of air in forming die cavity 23, porous insert 17 communicates the die cavity with a vacuum line 18, similar to the air withdrawal means discussed above.

Detonation of explosive charge 35 generates a pressure in explosion chamber 28 that is transmitted to workpiece 11 through a non-compressible medium 34, causing a uniform pressure to be transmitted to the entire area of workpiece 11 in communication or contact with non-compressible medium 34, whereby the workpiece 11 is formed to the shape of the forming die cavity 23. Because the velocity of the pressure waves through non-compressible medium 34 is slower than the velocity of shock and pressure waves through the ambient air of FIGURES 1, 2 and 7, the forming velocity is somewhat smaller using an explosion chamber than without a chamber. Because of this lower rate of forming there will be more drawing of the workpiece and less percentage of elongation than in the forming accomplished in FIGURES 1 through 4, 7 and 8. However, the forming velocity here is still above the rate of crack propagation for the workpiece material,

As can be seen from the above, the use of the apparatus and method as described above results in a high velocity forming of high strength materials without concern to their hardness at the time of forming or without concern as to their becoming hardened during forming. The forming forces are generated by the detonation of high explosives, the shock and pressure waves of which react against the workpieces to cause the material to flow to a formed shape controlled by a forming die. The forming operations in which the detonation shock and pressure waves contact the workpiece directly results in such forming being caused completely by the elongation of the workpiece subjected to such forces rather than having the forming take place by some draw in addition to elongation of the workpiece. There is both draw and elongation occurring in the forming operation indicated in FIGURES 5 and 6 where there is an intermediate medium for transmitting the high explosive detonation shock and pressure forces to the work material.

By employing high explosives having detonation rates of 4,000 meters or more per second, the velocity of forming by the shock and pressure waves forcing the workpiece material into the forming die cavity is at a rate faster than the rate of propagation of a crack or failure in the workpiece, thus causing the forming shape to be assumed before the elastic limit of the workpiece can be reached or before a crack or failure of the material can take place. This high speed forming velocity also eliminates any measurable springback of the workpiece. Thus, the exact shape of the formed workpiece will be the exact shape of the forming die cavity upon completion of the forming operation.

It is, of course, intended to cover by the appended claims all such modifications and equivalents as fall within the true spirit and scope of this invention.

What is claimed is:

1. A high explosive sheet and plate metal forming apparatus comprising, a die and a reflector member spaced vertically therefrom, the reflector member having a surface shaped substantially similar and opposite to the concavity of the die cavity, a high explosive charge affixed to the shaped surface of the reflector member having its over-all shape and dimensions in direct proportional relationship with the shape and dimensions of the die cavity, said reflector member surface arranged to face the die to direct shock and pressure waves generated by detonation of the high explosive charge between the die and the reflector member to a piece of metal on the die to force the metal to assume the shape of the die, and vacuum means extending through the die into communication with the die cavity to evacuate air in the cavity when the piece of metal to be formed is placed thereon prior to the detonation of the explosive.

2. The invention as defined by in claim 1 wherein the last mentioned means includes a porous insert nested in the die defining a portion of the cavity.

3. A high explosive sheet and plate metal forming apparatus comprising, a die and a reflector member spaced vertically therefrom, the reflector member having a surface shaped substantially similar and opposite to the concavity of the die cavity, a high explosive charge affixed to the shaped surface of the reflector member having its over-all shape and dimensions in direct proportional relationship with the shape and dimensions of the die cavity, said reflector member surface arranged to face the die to direct shock and pressure waves generated by detonation of the high explosive charge between the die and the reflector member to a piece of metal on the die to force the metal to assume the shape of the die, a porous insert fitted into the die and defining a portion of the cavity, a passage through the die communicating the porous insert exteriorly of the die, the insert and passage serving to exhaust air contained in the die cavity during the forming of the piece of metal.

4. A method of forming metals of sheet or plate shape to conform to a non-uniformly shaped cavity in the face of a die comprising the steps of, setting a piece of metal to be formed on the face of the die and over the non-uniformly shaped cavity, withdrawing air from the die cavity prior to forming to create a vacuum therein to establish a negative pressure area with respect to the area exterior of the die, shaping a charge of high explosive in the form of and proportional to the shape and dimensions of the die cavity, positioning the explosive charge symmetrically with respect to the cavity about a plane facing the cavity and parallel to the die face and between the cavity and the explosive charge, and detonating the charge of high explosive relative to the piece of metal to be formed whereby detonation shock and pressure waves of variable intensity dependent upon the shape of the explosive charge force the piece of metal to be formed into the negative pressure area of the cavity so that the piece of metal assumes the shape of the die cavity in an unenclosed and uncontained environment.

5. A method of forming work pieces of sheet or plate shape as set forth in claim 4, in which the explosive charge is placed on the work piece and the detonation and resultant forming occurs in an unenclosed and uncontained environment.

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