Sept. 21, 1965 N. N. IDA ETAL 3,206,963

METHOD AND APPARATUS FOR EXPLOSIVE FORMING OF METAL ARTICLES

Filed April 4, 1962 2 Sheets-Sheet 1

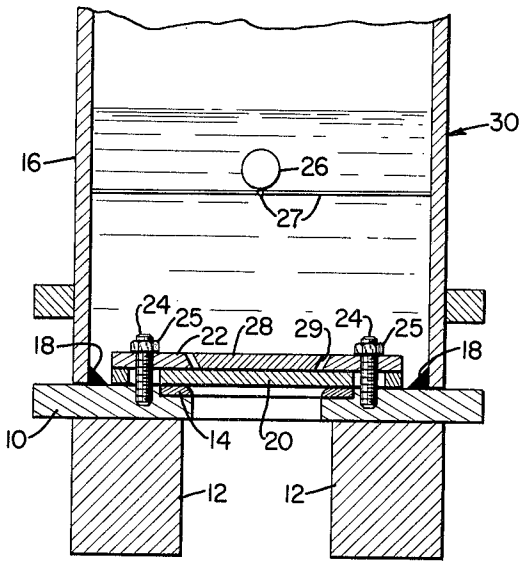


FIG. 1

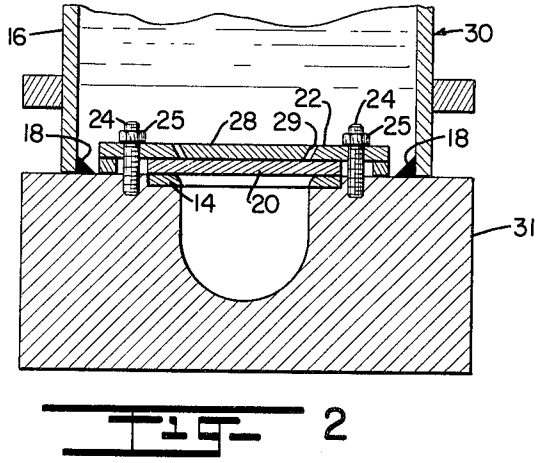
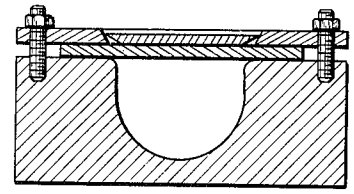


FIG. 2



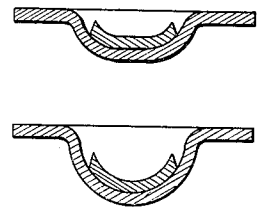


FIG. 3

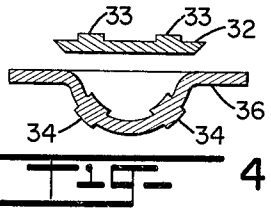


FIG. 4

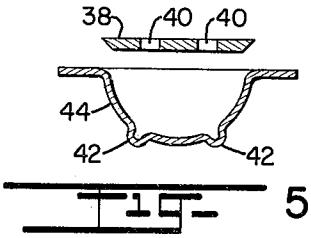


FIG. 5

INVENTOR.
NOBLE N. IDA
JACK T. SNYDER,
BY
Philip H. Sheridan
ATTORNEY

Sept. 21, 1965 N. N. IDA ETAL 3,206,963

METHOD AND APPARATUS FOR EXPLOSIVE FORMING OF METAL ARTICLES

Filed April 4, 1962 2 Sheets-Sheet 2



FIG. 6

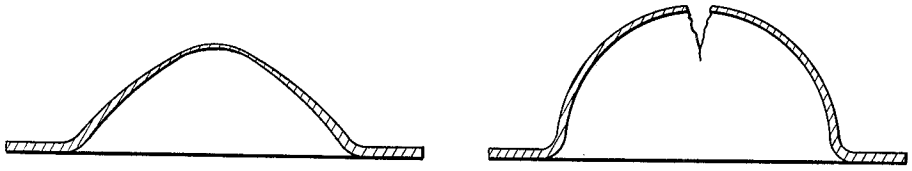


FIG. 7

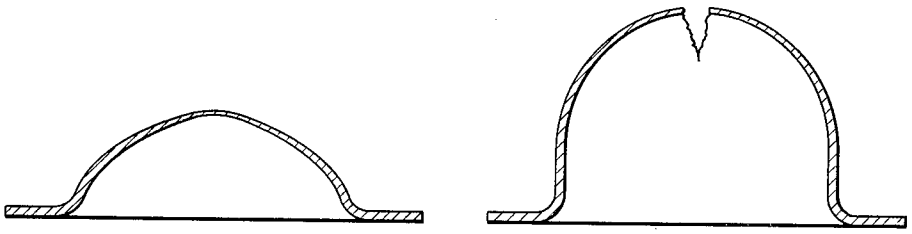


FIG. 8

INVENTOR.
NOBLE N. IDA
JACK T. SNYDER
BY Philip H. Sheridan
ATTORNEY

United States Patent Office 3,206,963 Patented Sept. 21, 1965

3,206,963

METHOD AND APPARATUS FOR EXPLOSIVE FORMING OF METAL ARTICLES

Noble N. Ida, Boulder, and Jack T. Snyder, Littleton, Colo., assignors to Martin-Marietta Corporation, Baltimore, Md., a corporation of Maryland

Filed Apr. 4, 1962, Ser. No. 185,077
8 Claims. (Cl. 72—56)

This invention relates to an improved method and apparatus for the explosive forming from metal blanks of articles of required shapes.

As explosive forming of metal parts is conventionally performed, a metal blank which is to be formed into the required shape is positioned over the opening in a die which is ordinarily located in a fluid medium and a spherical shock wave is initiated in the fluid from a point source explosive charge and permitted to impinge upon the contact surface of the blank to form it into the required shape. The blank may be restrictively formed into a female die or it may be permitted to "free form" in air as the case may be depending upon whether or not a restrictive die forming or free forming technique is being used.

The phenomena accompanying explosive forming differ significantly from those associated with conventional die forming techniques using male and female dies. For example, explosive forming produces pressures in the range from 100,000 p.s.i. to 1,000,000 p.s.i. in contrast to those produced by conventional techniques which are in the neighborhood of a maximum of 100,000 p.s.i. Further, metal formed by explosive forming moves at rates up to 1,200 to 2,500 feet per second as compared to a movement rate of approximately 100 inches per minute for metal formed by conventional techniques.

Explosive forming offers a number of attractive possibilities to the metal forming art particularly in the area of forming large hemispherical parts. It is ordinarily not feasible to form large hemispherical sections by conventional techniques because of the expense involved in manufacturing large dies. Such parts are ordinarily made by welding sections together. Explosive forming of such sections by free forming techniques suggests the possibility of eliminating the necessity for large dies or for making these large hemispherical parts in welded sections. Elimination of the necessity of a female die by use of the free forming technique likewise eliminates the necessity for expensive facilities for evacuation of the die cavity. Further, the use of explosive forming techniques suggests the attainment of complicated shapes provided control over the movement of the metal being formed can be attained.

There are a number of other disadvantages associated with explosive forming techniques which it is the objective of this invention to overcome, some of them being somewhat interrelated. A significant problem in explosive forming is that of thin-out, that is, nonuniform thinning of the metal as it is expanded. This of course results in a product having walls of nonuniform thickness so that milling operations are necessary to provide a wall of uniform thickness throughout. A further defect of explosive forming techniques presently being used is that a significant nipple is formed at the apex of formed domes resulting in a shape which is neither elliptical or hemispherical. The nipple results from relative excessive expansion and consequent thinning of metal at the apex and is caused by relative excessive pressure in this area. Nippling effects result in tension failures which in turn limit the depth of draw which can be attained from a metal blank of given dimensions. Depth of draw may be referred to as the distance from

the base of the flange to the apex of the formed part which can be attained without tension failure.

The present invention comprises an improved method of explosive forming by which the pressure profile on the contact surface of the metal blank to be formed is controlled and localized to provide for application of maximum pressures in areas where maximum deformation is required. Stated another way, the improvement lies in locally deflecting the uniform shock wave produced by an explosive charge in such a manner that the energy derived in the form of work is concentrated locally in desired areas, specifically, areas where maximum deformation is required. Since the resultant energy produced by explosives, for example, in the forming of hemispherical domes, is used to deform a flat metal surface into a dome shape, the integral amount of work produced is measured directly as amount of strain (thinning in this case) introduced into the flat stock. Since the amount of strain occurring in a metal under deformation is a direct function of a cross-sectional mass, it follows that a uniform energy output to a forming system may be controlled to locally produce heavy areas of work in any area specified by changing the mass configuration at these areas.

Control of the energy input in the present invention is achieved by use of a flexible plug cushion of solid material positioned over the contact area of the metal blank which is to be deformed, the plug being designed to leave the selected areas of maximum local deformation uncovered. In the case of forming hemispherical parts, the effect of the plug cushion is to localize maximum input energy to the metal in the area of the edge of the die, this being the area where maximum deformation is desired.

The invention will be explained in conjunction with the drawings in which like numerals refer to like parts:

FIG. 1 is a cross section of apparatus employed in practicing the invention;

FIG. 2 is a fragmentary view of a section of FIG. 1 showing a modification of the apparatus of FIG. 1;

FIG. 3 is a time sequence illustration of explosive forming with the use of a plug cushion;

FIG. 4 is a cross section of a modified plug cushion and article formed with its use;

FIG. 5 is a cross-sectional view of a further modification of a plug cushion with a showing of the part it is designed to produce;

FIG. 6 is a comparative showing on nippling effect, the drawings being made from photographs of hemispherical domes produced by a standard method and the method of this invention;

FIG. 7 is a comparative showing of thin-out effect, the drawings being made from photographs of sections of domes produced with a standard method and the method of the present invention; and

FIG. 8 is a comparative showing on depth of draw, the drawings being made from photographs of sections of domes produced by a standard method and the method of the present invention.

The metal used in making the parts depicted in FIGURES 6, 7 and 8 was 0.050 inch aluminum alloy stock.

Referring now to FIG. 1, a draw ring **10** is mounted on foundation or support members **12**. The draw ring is provided with a circular opening in its central portion as shown. A die ring **14** having an opening with a diameter equal to that of the draw ring is seated around the opening in the draw ring. The draw ring and die ring are preferably of metal. The internal edge of the die ring **14** is symmetrically rounded and the axis of curvature of the internal edge is referred to herein as the die axis. Alternate equivalent die forming equipment may be used. A circular container wall **16**, preferably of metal, is se-

cured to draw ring **10** in fluid-tight relationship by means of weldments **18** or other equivalent means. A work blank **20** of metal to be formed into the finished article is clamped over the die opening by means of clamping ring **22**, studs **24** and nuts **25**. A spherically shaped high explosive charge and a suitable initiator therefor, shown schematically at **26**, are mounted on crossed wires **27** as shown. Plug cushion **28** having a diameter substantially that of the opening in die ring **14**, is positioned over the area of the work blank **20** which is to be formed. The arrangement of the work blank clamped to the die ring constitutes a fluid-tight arrangement and with wall **16** provides a fluid-tight container. The container **30**, comprising wall **16** and work piece **20**, is filled with water to complete the apparatus for practicing the method of the invention.

In the free forming technique of the invention the metal is expanded in air rather than into a restricted die, such as a female die. In practice, the explosive is detonated to form a spherical front shock wave which is transmitted through the fluid to the work blank. Free forming without the use of the plug cushion **28** under ideal conditions would theoretically result in a shape conforming to a fourth degree paraboloid of revolution. Use of variously designed plugs results in correspondingly shaped products.

The invention is not restricted to any particular metal for forming but all types of metals may be shaped with the method described. The dimensions of the blank will depend upon the dimensions of the product required. Such parameters as stand-off distance, thickness of the blank, degree of bevel, and others, are determined by well-known scaling laws which have been developed for this purpose. A ration of blank diameter to die diameter of at least 1.4 or greater has been found to be satisfactory. It was found that finger-tight torque on nuts **25** provided adequate pressure between the clamping ring and the work blank. This amount of torque was found to permit adequate slippage to prevent buckling.

Although metal is preferred as the material for plug cushion **28**, the invention is not restricted to the use of this material. It is a requirement of the plug material that it be ductile so that it will deform in obtaining the desired mass effect with the metal blank. The effectiveness of the plug is a function of the density of the material from which it is made. Plugs of lead, aluminum and aluminum alloys have been satisfactorily tested. The plug is preferably constructed with a diameter conforming to that of the die opening. The plug edges are preferably beveled or chamfered as shown, as it has been found that bevel angle is directly proportional to deflection before failure. The shape of the curve of the finished product can be controlled by the angle of bevel provided the proper blank thickness is used. For example, it has been found that an angle of 30° on the bevel with the required blank thickness results in an elliptically shaped product. The angle would be proportionately increased for an article with a steeper curve. The plug is not attached to the blank during forming but lies loose thereon. A lubricant may be used between the plug and the contact surface of the metal blank to prevent slippage.

The fluid medium used is not restricted to water but may be any desired fluid. Oil, suspensions, emulsions, or even heavier fluids may be used depending upon the degree of damping required of the fluid. For effective results the fluid is preferably contained.

The type of high explosive used is not critical but any suitable high explosive may be used. An example of a satisfactory explosive is dynamite. The amount of explosive required for a desired depth of draw is, of course, computed by conventional scaling techniques which take into consideration the various pertinent parameters. The explosive is preferably positioned directly above the center of the plug cushion. The distance of the explosive from the surface of the plug cushion will be determined by the characteristics desired in the formed product and will again be calculated by well-known scaling techniques. The explosive is in the form of a spherical shaped charge to provide a point source of energy which will produce a spherical shock wave.

In FIG. 2, apparatus is shown for application of the improved explosive forming method in which a restrictive die, or female die, **31** is used. The depth of this die will, of course, depend upon the depth of draw required in the forming step.

FIG. 3 depicts a time sequence showing of the explosive forming of a blank utilizing the plug cushion. The corresponding deformation of plug and blank is clearly illustrated.

Referring to FIG. 4, a modification **32** of the plug cushion is shown provided with thickened portions **33** to provide corresponding thickened portions **34** in formed blank **36**. This is an example of complicated shapes which can be made utilizing the invention. The strengthened portions **34** would be useful as reinforced areas for attachment of parts.

Referring to FIG. 5, there is shown an additional modification **38** of the plug cushion in which holes or thinned out portions **40** are provided for forming thin wall metal protuberances **42** in article **44**. The article **44**, for example, could take the form of a missile propellant tank and the protuberances might serve as filling spouts after being properly equipped with openings and lids.

Referring to FIG. 6, a comparative showing is made of a hemispherical section on the left side of the drawing made by a conventional explosive forming method and such a section on the right side of the drawing made by the present method. It will be noted that the article on the right takes the form of a perfect hemisphere with no indication of nippling while the effects of nippling are apparent in the article on the left with its reduced radius of curvature. The effect of the plug cushion used to make the article on the right is to provide for maximum expansion of metal at the juncture of the flange and the hemisphere rather than in the area near the apex of the article. In practice, the flange of the article on the right would be trimmed from the hemispherical part to provide for uniform thickness in the wall of the remaining hemisphere.

Referring to FIG. 7, a comparative showing of uniformity of wall thickness, the varying wall thickness of the article on the left is striking when compared with the uniform wall thickness of the article on the right. The article on the left was made by a conventional explosive forming process while the article on the right was produced by the present process. Wall thin-out was reduced to 6 percent for the article on the right as compared to a thin-out of 33 percent before rupture for the article on the left. This comparative showing illustrates the improvements in this problem area which can be obtained by the present method of localizing applied pressure to the area of the blank near the edge of the plug cushion.

Referring now to FIG. 8, the improvement in depth of draw achieved by the present method is graphically illustrated. The article on the left was made utilizing conventional explosive forming techniques while the present method was used to make the article on the right. The depth of draw achieved in the article on the left was approximately 2.2 inches as compared to a depth of draw of approximately 4.5 inches before rupture for the article on the right. In other words, a depth of draw is obtained with the present method almost twice that which can be obtained with conventional methods.

The above showings of results obtained by the method of this invention illustrate the results which can be achieved through local control of metal mass movement in explosive forming. Blanks up to two feet in diameter have been free formed into true hemispherical parts using this method. The method has been shown to provide a product having improved thickness uniformity

over its entire circumference. Articles having almost true hemispherical and elliptical shapes have been produced and a two-fold increase in allowable shell depth over conventional methods has been achieved.

Shells of uniform thickness eliminate such costly procedures as taper "chem-milling" and taper machining which are currently necessary to provide uniform thickness in shells made by conventional processes. Metal mass movement control during explosive forming as provided by the instant invention means that shells can be fabricated with desired varying thickness to provide thin areas and reinforced areas as required. The resultant consequence of the elimination of costly, cumbersome dies or of welding sections together to form large diameter shells emphasizes the significance of the invention. The potential provided by the invention for forming dimensionally accurate hemispherical and elliptical domes of large-scale dimensions to meet the demand for missile construction is highly important.

The method of the invention increases metal formability resulting in the use of thinner blanks with the result that less expensive forming apparatus is required. Further, the method provides a potential for explosive forming of metal which is at the final desired temper thus removing the requirement of heat treating the metal to the desired temper after forming with the consequent risk of warping of the formed article.

It is to be understood that the present invention is not to be limited to the precise details of construction and arrangement as hereinbefore set forth as it is obvious that various modifications and changes may be made therein without departing from the essential features thereof as defined by the appended claims.

What is claimed is:

1. The method of forming and shaping metal blanks to required shapes which comprises clamping a blank of metal from which the part is to be shaped over an opening in a die with its periphery extending beyond that of said opening at all points, positioning a freely movable plug of ductile material of substantially the same size as said opening over the blank so that the peripheries of said plug and said opening substantially coincide, containing a fluid medium contiguous to the contact surface of the plug, and initiating a spherical shock wave in said fluid medium at a point removed from said plug and substantially opposite the center of the plug whereby the shock wave impinges on the contact surface of the plug to form the blank.

2. The method of claim 1 in which the forming of the blank is restricted.

3. Apparatus for the explosive forming of metal comprising in combination, support means, die forming means associated with said support means defining a die opening, clamping means for clamping a work piece over said die opening, a container wall mounted on the top of said support means over said die opening and adapted to form a container for holding fluid with said top and said work piece serving as its bottom when said work piece is clamped over said die opening, explosive means positioned in said container wall at a point above said die opening, means for the initiation of said explosive means to form a shock wave, and a substantially flat plug of pliable solid material adapted to be loosely positioned on the contact surface of a work piece clamped over said die opening and of a size and shape such that its periphery corresponds substantially to that of said opening when so positioned for controlling the pressure profile of said shock wave following initiation of said explosive to provide for maximum work being done by the shock wave on the area of a work piece adjacent the edge of said die opening when a work piece is clamped over the top of said opening prior to said initiation.

4. The apparatus of claim 3 in which the edges of the plug are chamfered.

5. The apparatus of claim 4 in which the edges of said plug are chamfered at an angle of 30°.

6. The apparatus of claim 3 in which the chamfer slopes inwardly from the shock wave contact surface of the plug.

7. Apparatus for the explosive forming of metal comprising, in combination, support means, die forming means on said support means defining a die opening, clamping means for clamping a work piece over said die opening, a container wall mounted on the top of said support means over said die opening and adapted to form a container for holding fluid with said top and said work piece serving as its bottom when said work piece is clamped over said die opening, explosive means positioned in said container wall at a point above said die opening, means for the initiation of said explosive means, and means adapted to be placed on the contact surface of said work piece for cushioning said area of said work piece wherein comparative minimum local movement of metal is desired from the shock wave resulting from initiation of said explosive when a work piece is clamped over the top of said die opening prior to said initiation.

8. In apparatus for the explosive forming of metal in which a spherical shock wave is used to deform a metal blank supported over a die opening, the improvement which comprises a plug cushion of ductile solid material of substantially the same size as the die opening loosely positioned on the shock wave contact surface of the metal blank with its periphery substantially coinciding with that of the die opening.

References Cited by the Examiner

UNITED STATES PATENTS

2,935,038	5/60	Chatten	113—44
2,983,242	5/61	Cole	113—44
3,036,374	5/62	Williams	113—44

FOREIGN PATENTS

1,265,540	5/61	France.

OTHER REFERENCES

"American Machinist," June 15, 1959, page 127.

"Stampings for the Space Age," by Throner and Liberman, published in The Tool and Manufacturing Engineer, May 1961, pages 123–126.

CHARLES W. LANHAM, *Primary Examiner.*

WILLIAM J. STEPHENSON, *Examiner.*