May 29, 1962 V. W. DREXELIUS 3,036,373

METAL FORMING

Filed March 31, 1959

2 Sheets-Sheet 1

FIG. 1

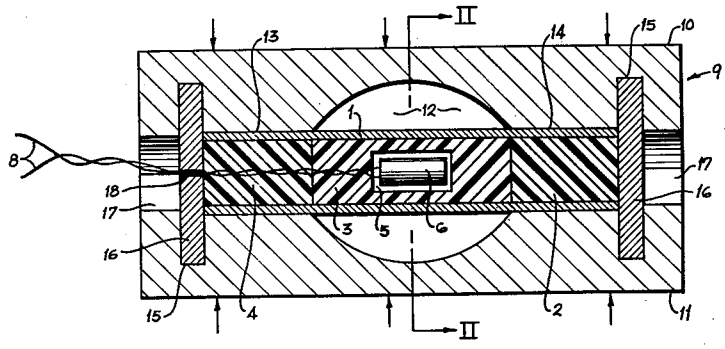


FIG. 2

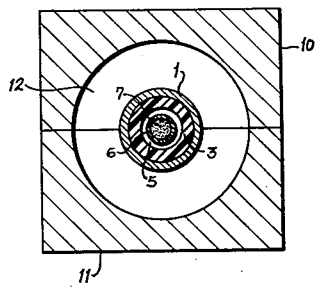


FIG. 3

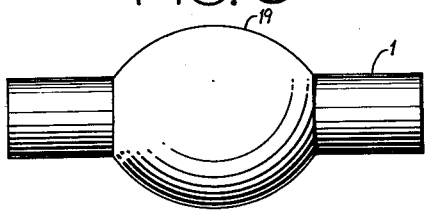


FIG. 4

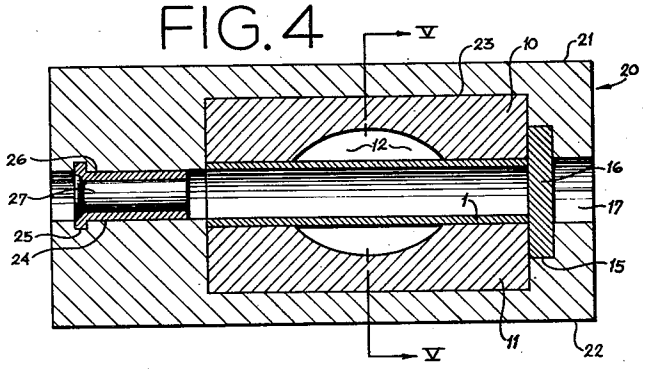
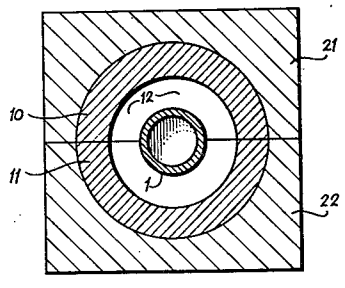


FIG. 5



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Filed March 31, 1959 2 Sheets-Sheet 2

FIG. 6

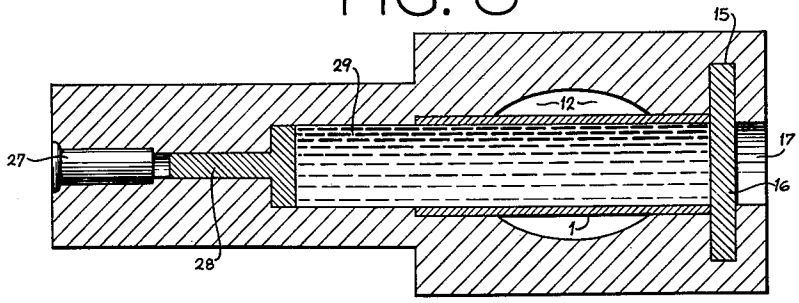


FIG. 7

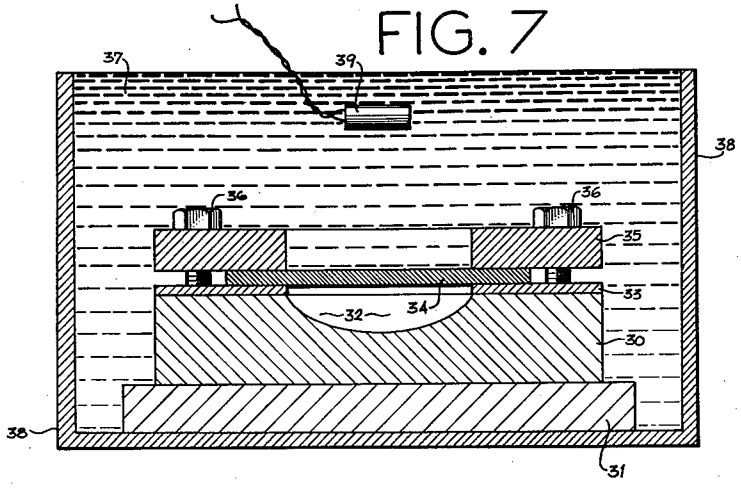
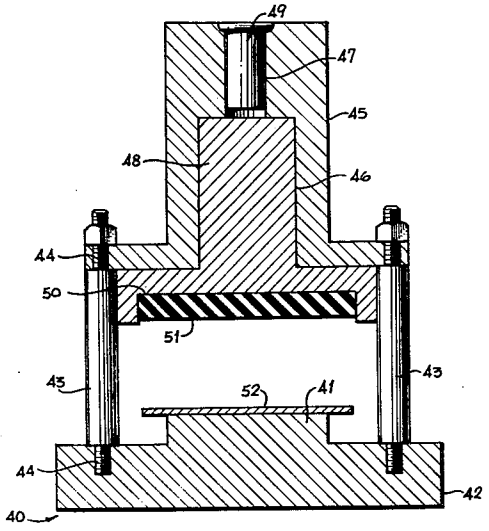


FIG. 8



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3,036,373

Patented May 29, 1962

3,036,373

METAL FORMING

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Filed Mar. 31, 1959, Ser. No. 803,313
11 Claims. (Cl. 29—421)

This invention relates to the deformation of metal, and more particularly to the deformation of metal by high pressures produced by the initiation of explosives.

Heretofore the working of metal has been accomplished by the familiar cupping, drawing, extruding, dimpling or swaging operations conventionally in current use. However, these operations have been found to be inadequate for working of metals demanded in highly advanced technological fields. For example, the aircraft industry has made tremendous strides in recent years relative to service ceilings and speed of aircraft. These advances plus future anticipated advances require, for continued improving performances, lighter, stronger and tougher materials with decreased dimensional tolerance of component parts. Many of these parts cannot be manufactured to specifications employing present conventional methods. As disclosed on pages 112 to 115 in the January 14, 1957 issue of the American Machinist, the metals presently demanded for the aircraft industry necessitate not only the working of tough hard-to-work metal such as titanium alloys, but also the forming of the metal into complex shapes and curvatures, which render the conventional hydro-press, drop-hammer and other conventional methods impractical. A particular disadvantage in working of certain metals is the prohibitive amount of spring-back experienced on pressure release of conventional equipment. In addition, the use of conventional methods in forming operations often require the use of secondary finishing operations. Also, metals such as various titanium alloys, Monel metal and various stainless steels cannot be adequately worked by the conventional methods enumerated above without elaborate and expensive auxiliary equipment and processes.

Inasmuch as more drastic advances are contemplated in various technological fields in addition to aircraft, as for example missiles and rockets, working the metals to the contours and curvatures required can be satisfied only by more drastic methods of working, as for example the utilization of explosive charges.

It has been discovered in research with the forming of metals with explosives that the forming of metals, heretofore considered impossible, can be accomplished by controlling the rate of pressure application, of explosive forces, so that the rate of metal formation is in excess of the rate of propagation of fractures, of the metal, so that the material can be readily formed. The rate of pressure application, in accordance with this invention, is such that the explosive shock does not shatter the metal to fragments nor does it prevent forming of the metal to the final and ultimate dimensions desired eliminating needs for additional finishing operations. This is accomplished by supplying an explosive force capable of generating and exerting a sufficient pressure within a maximum time interval of 10 milliseconds, to the portion of the metal desired to be deformed, to deform the aforesaid portion of metal at a critical velocity of deformation which is at least 10 feet per second. In the application of this invention to the forming or working of metal with low energy explosives, the pressures generated will be of the order of 500 to 75,000 pounds per square inch applied within a maximum time interval of 10 milliseconds to the portion of the metal to be deformed wherein the aforesaid portion of metal is of sufficient strength to restrain its velocity of deformation, under

the impact of the applied pressure, within the range of 10 to 25 feet per second. Although the aforesaid ranges of pressure, generated within a maximum time interval of 10 seconds, and metal velocity provide the desired result with low energy explosives, optimum results with low energy explosives are obtained by the application of pressures within the range of 1,000 to 10,000 pounds per square inch within a time interval of 5 milliseconds to move the portion of the metal to be deformed at a velocity of substantially 14 feet per second.

Although the invention will be described with particular references to the use of low energy explosives, it is to be understood that the invention is equally applicable to high energy explosives which generate pressures up to the order of millions of pounds per square inch, for example 7½ million pounds per square inch, within a time interval measured in microseconds as short as 1 microsecond provided, however, that it is equally applied and so that the velocity of the metal undergoing deformation is at least 10 feet per second. As will be understood, use of high energy explosives requires modification of the equipment employed in forming or working metals with low energy explosives. For example, the force of low energy explosives may be contained within a suitable enclosed chamber such as a combustion chamber. The force of high energy explosives is extremely difficult to be contained within an enclosed chamber and is generally for convenience and safety initiated whereby the explosive forces may be dissipated into the atmosphere to hold the pressure application equally to the desired level in this or any other suitable way.

In accordance with this invention, the portion of the metal worked is believed to be moved during conditions of plastic flow which prevent the accumulation of excessive residual stresses which prevent fragmentation of the metal with extremely little, if any, spring-back eliminating the need for secondary finishing operations. The simplified technique of this invention eliminates the need for large and expensive forming equipment, provides uniform configurations from part to part and eliminates spring-back associated with prior explosive and other methods.

The forming of metals by explosives in accordance with this invention may be accomplished by employing either female or male dies with the blank being forced into the female die or over the male die by means of an explosive charge either attached to or closely adjacent a metal blank. Water, plastic material or other hydraulic media may be used as a means for uniformly distributing the shock and pressure waves. Also a vacuum or some appropriate venting means is generally employed for removal of air behind the blank to insure positive freedom from air entrapment during the explosive forming cycle. By hydraulic media herein is meant various substances such as liquids, elastomers, tars, putty, soft clays, muds and low melting materials such as wax, aluminum, lead and woods-metal which are capable of undergoing movement under the explosive force to function, in effect, as a hydraulic medium.

Accordingly, it is an object of this invention to provide a novel process of metal forming eliminating disadvantages of the prior art.

Another object of this invention is to provide a novel process that may be used to form parts which cannot be formed by conventional methods.

Still another object of this invention is to provide a novel process which reduces the complexity and cost of sheet metal and tubular forming devices and techniques presently in use.

A further object of this invention is to provide a novel process which reduces hand finishing and other secondary operations.

A still further object of this invention is to provide a novel process adaptable for rapid expansion of production rates of hard-to-form shaping operations.

A still further object of this invention is to provide a novel process in which metal is deformed with substantially no-spring-back due to recognized characteristics of the material.

Other objects and advantages will become apparent from the following description and drawings in which:

FIGURE 1 is a cross sectional view of an embodiment of this invention employed for the bulging of a metal tube;

FIGURE 2 is a cross-sectional view taken along line II—II of FIGURE 1;

FIGURE 3 illustrates a bulged tube obtained in the embodiment of FIGURE 1;

FIGURE 4 is a cross-sectional view illustrating another embodiment of applicant's invention for the metal forming of a tube similar to that obtained in the embodiment of FIGURE 1;

FIGURE 5 is a sectional view taken along line V—V of FIGURE 4;

FIGURE 6 is a cross-sectional view of still another embodiment of this invention for the working of a tube into a configuration similar to that obtained in FIGURE 1;

FIGURE 7 is a cross sectional view of a further embodiment of this invention adapted to the application of high energy explosives in illustrating a method for working a metal plate into a female die; and

FIGURE 8 is a cross-sectional view of a further embodiment of this invention employed in the working of a metal plate about a male die.

Referring to the drawings and with reference to a copending application of Vernon C. Moehlman, Serial No. 801,262 filed March 23, 1959, a tube **1** of 3½ inches diameter by 20 inches length having a 0.025 inch gauge was fabricated from AISI 321 stainless steel having the following composition: Carbon, 0.80 maximum; Chromium 17.00 to 19.00; Nickel, 8.00 to 11.00; and Titanium, 5×C minimum. The interior of the tube is filled with a number of plugs **2**, **3** and **4** of elastomeric media, such as a vinyl chloride resin, to serve as a force transmitting media for subsequent metal forming of tube **1**. The preformed shape of the aforesaid media is of cylindrical form in which two of the plugs, **2** and **4**, are solid with the preform of plug **3** being provided with an internal chamber or cavity **5** for insertion of a suitable container of explosives. In addition, preform or plug **3** is further provided with some convenient means, such as a slit, for inserting a container of explosives **6**.

The explosive charge **7** to be used for forming the tube **1** may be contained in any suitable container, such as a conventional polyethylene bottle provided with an orifice screw cap for entry of electrical wires connected to an appropriate squib, containing a black powder and the like, with material such as cotton filling, if desired, the head space above the explosive charge **7**. As will be understood, the explosive charge need not be placed within a case since the explosive may be employed as a solid shaped charge. The explosive charge may be of any suitable composition provided it generates a sufficient explosive force to exert sufficient pressure within a maximum time interval of 10 milliseconds on the portion of the tube to be deformed to deform the tube walls outwardly at a velocity of at least 10 feet per second. However, as noted above, the explosive charge employed in the instant illustrative example is a low energy explosive which, as said above, must be capable of generating a force, generally within the range of 500 to 75,000 pounds per square inch, within a maximum time interval of 10 milliseconds to deform the metal to exert a pressure on the metal to deform it at a velocity of at least 10 feet per second. Preferably, with low energy explosives, the pressure is within the range of 1,000 to 10,000 pounds per square inch and will deform the tubular walls outwardly at a velocity between 10 and 25 feet per second. Within the preferred range optimum results are obtained if the low energy explosive generates the pressure range, 1,000 to 10,000 pounds per square inch within a maximum time interval of 5 milliseconds to deform the metal at a velocity substantially 14 feet per second.

As will be understood, the quantity of the explosive charge can be readily correlated, by those skilled in the art, in relationship to the thickness of the tubular walls, of the instant example, and to the area of the tube to be deformed in order to provide the aforesaid pressures within 5 milliseconds to obtain the desired rate of deformation. The specific low energy explosive charge employed in the instant illustrative example was 350 grains of powder prepared by formulating 80% by weight of nitrocellulose with 20% by weight of nitroglycerin.

In addition, various other types of explosives may be used in practicing the invention provided they generate the desired pressures within a maximum time interval of 10 milliseconds to move the metal to be deformed at a velocity at least 10 feet per second. Other explosives, commercially available from the Olin Mathieson Chemical Corporation, are those identified as X–1193 of the following composition: 55% nitrocellulose plus 45% nitroglycerin, and WC 857 of the following composition: 90% by weight of nitrocellulose with 10% by weight of nitroglycerin, and WC 235H of the following composition: 60% nitrocellulose plus 40% nitroglycerin.

The resilient plugs **2**, **3** and **4** are inserted within tube **1**, as indicated in FIGURE 1, with the lead wires **8** threaded through a convenient opening in the vinyl chloride resin plugs **3** and **4**, after which the assembly is then placed within a split female die **9**.

Die **9** consists of two identical portions **10** and **11** having their interior portions machined to provide a cavity **12**, defining the bulge desired to be formed in tube **1**, and bores **13** and **14** conforming to the dimension desired in the unbulged portion of the tube. The die portions **10** and **11** are also provided with peripheral grooves **15** in which are mounted steel inserts or seals **16**. Although not essential, the ends of the die portions are adapted to provide, upon assembly, circular openings **17** for convenience in reaching circular inserts or seals **16**, for example, where a bleeding means is provided for the pressures developed within the die assembly.

A small opening **18** is provided in one of the inserts **16** for lead wires **8**, which opening is sealed after threading through of the leads. The die assembly is then placed within any convenient clamping means capable of exerting a sufficient force to hold the assembly together against separation on the initiation of the explosive charge **7**. The clamping means may be obtained by a series of nuts and bolts disposed about the perimeter of the die portions, or the assembly may be placed within any convenient hydraulic press. The pressure exerted by the clamping means employed also performs an additional function of maintaining die portions **10** and **11** and inserts **16** in sealing relationship to each other in order to contain the combustion products of the explosive charge within the assembly.

The die assembly was then placed within a 150 ton hydraulic press which was adjusted to slowly build up to exert a pressure of 100 tons on the die assembly. To insure against any possible malformation of tube **1** due to air being trapped between the tube and the die walls, the die was connected to a vacuum pump, not shown, which pulled at least 25", mercury, of vacuum in the die. Relief of any possible cushion of air between the tube **1** and the die walls may be also obtained by providing vent holes of the order of 1/16 inch diameter. The provision of these vent holes, under certain conditions, may be provided with added advantages where perforations are desired in the bulged tube walls. In such a situation, the vent holes may be conveniently provided at the points where the perforations are desired in the bulged tube walls

whereat the explosive perforates, together with forming, the walls of the tube.

With the die assembly within the clamping means, the explosive charge is initiated by making an appropriate electrical contact across leads 8 whereupon the explosive charge is ignited. The force of the exploded charge causes the vinyl chloride resin to expand to transmit the explosive force to the metal tube walls exerting a pressure of approximately 5,000 pounds per square inch within the preferred time interval of 5 milliseconds thereby pushing and forcing the metal of the tube out to and against the configuration of the die cavity 12 at a velocity between 10 and 25 feet per second. The tube in this manner has imparted to it a bulge 19 conforming with precision to cavity 12 of die assembly 9, with no measurable spring-back.

As will be understood, the velocity of deformation will be dependent upon the specific quantity of explosive used, and therefore, upon the pressures generated. In practice, variation, within the normal limits of operation, occur in the quantity of explosives employed with consequent variation in resultant pressures and deformation velocities of the metal. Accordingly, the example sets forth the conditions of operation which give the optimum correlation of pressure range with the range of velocity deformation of the metal wherein the pressure is generated within the optimum maximum time interval of 5 milliseconds.

These advantages of conformance to the configuration of the forming die and the absence of any measurable spring-back result from the application of a particular pressure level within a definite time interval, 5 milliseconds, to move the metal at a forming speed, under the impact of the applied pressure, between 10 to 25 feet per second and preferably 14 feet per second. Thus, metal forming in accordance with this invention is believed to cause the metal to move during conditions of plastic flow which prevent the accumulation of excessive residual stresses, and preventing spring-back of the formed metal, and at a rate of metal formation in excess of the rate of propagation of fracture preventing the pressure wave from shattering the metal to fragments. Appreciation of the drastic difference between the velocity of the metal during forming, in accordance with this invention, can be readily observed from the following table.

	Forming Speeds of Metal in Accordance with this Invention (Feet per Second)	Typical Speeds of Conventional Methods of Drawing Metal (Feet per Second)
Aluminum	At least 10	2.9
Brass	do	3.3
Copper	do	2.5
Steel	do	0.91

Although the invention was described, above, with relationship to a particular alloy, it is to be understood that it is readily applicable to other metals such as AISI 304 or 310 stainless steels. For example, tubes of the above metals of 0.035 inch side wall thickness gauge having a diameter as large as 6⅜ inches and 31 inches in length can be readily formed or worked without any measurable spring-back. In practice, production items of these aforesaid tubes have been and are held to a very close tolerance and scrap has been reduced to a minimum. The application of this invention is not restricted to tubing and is readily applicable to the working of flat metal stock. A dimple of 1 inch depth on a 3T radius was readily formed in a 0.090 inch thick flat sheet of 5086–H34 aluminum alloy.

In practice, the pressure generated in the expansion, in the die assembly of FIGURES 1 and 2, was gradually released by slowly relieving the force of the clamping action maintained on die assembly 9. However, if desired as noted above. an appropriate bleeding action may be provided in either die portion 10 or 11 or in one or both of the inserts 16 to relieve the contained pressure within the assembly. After equalization of the pressure within the die and the surrounding atmosphere, the die was opened and the bulged tube 1 removed. The vinyl chloride resin force transmitting media was then removed by pushing it out. Upon inspection of tube 1, the bulge 19 imparted to the tube, has a 4 inch O.D. and was found to exactly conform to the cavity dimensions of the die with no measurable spring-back.

Although the invention has been described with specific reference to the use of an intermediate medium for the transmission of the explosive forces to the metal, FIGURE 4 illustrates an embodiment of the invention in which the explosive force acts directly against the work piece, tube 1, to force it against the contour of the forming die formed by portions 10 and 11. In this embodiment, the die assembly formed by die portions 10 and 11 is contained within an enclosing retainer 20. The retainer 20 is formed of two identical portions 21 and 22 provided with a recess 23 to accept the split female dies and is provided with peripheral grooves 15 in which are mounted steel inserts or seals 16 readily accessible through a circular opening 17. A bore 24, in the other end of retainer 20, communicates with recess 23, and is provided at its extreme end with a peripheral groove 25. Bore 24 and groove 25 are adapted to receive a breech mechanism 26, which in turn is adapted to receive a cartridge 27 containing the explosive charge in accordance with this invention. To prevent the entry of air between the metal tube and the forming die, a suitable sealing means, known to those skilled in the art and not shown, may be provided. In this embodiment the explosive force acts directly against the inner tubular walls to develop a pressure within the range of 500 to 75,000 within a maximum time interval of 5 milliseconds to force the tube at a velocity between 10 to 25 feet per second against the forming die.

FIGURE 6 illustrates another embodiment of an application of this invention in which the explosive forces act against a piston 28 which in turn presses against an intermediate medium other than a solid, for example a liquid 29 such as water.

FIGURE 7 illustrates a further embodiment of this invention adapted to the application of high energy explosives in the forming of dish shaped sheet metal structures. A female die 30 extends upwardly from a base 31 to which it is suitably secured by any convenient method. Provided on its upper surface of die 30, about its cavity 32, is a sealing ring 33. Work piece 34 is mounted on die 30 by means of a hold-down ring 35 secured to die 30 by means of a nut and bolt assembly 36. The die assembly with the work piece 34 is submerged in a liquid 37, such as water, contained within a suitable tank 38 to open to the atmosphere. Although a liquid, such as water is illustrated, it is pointed out that the explosive force may be transmitted through air, in the absence of liquid, provided sufficient explosive is employed to provide the conditions required in accordance with this invention. A suitable explosive charge 39, such as PETN, contained in a waterproof container is submerged in liquid 37 above the die. In this example of the invention, the high energy explosive generates an explosive force, within one microsecond, which is transmitted, through liquid 37, to the work piece 34 at a pressure sufficient to drive the work piece 34 downwardly at a velocity at least 10 feet per second against the configuration of the die cavity 32. As will be understood, the container 38, or the die assembly and/or work piece 34 may be in their horizontal cross-section of any configuration, eliptical, rectangular or circular.

In practice according to the embodiment depicted in FIGURE 7, with use of cylindrical female dies, a number of ⅝ inch thick tubes fabricated of 17–7PH stainless steel of 37 inches in diameter and 17 inches in height have been readily worked in accordance with this inven-

tion. Also low carbon 1015 AISI steel of ¼ inch thickness has also been successfully formed with 25% elongation and no measurable spring-back.

Although the preceding embodiments have been described in relationship to the working of a metal against a female forming die, FIGURE 8 illustrates still another embodiment of this invention illustrating the working of metals against a male die. A male die **40** is provided with a forming portion **41** extending upwardly from a base **42**. Secured to base **42**, of die **40**, by an appropriate screw threaded arrangement **44** on spacer and support post **43** is a breech assembly **45**. The breech assembly **45** is provided with communicating bores **46** and **47** for reception of a piston **48** and a cartridge **49**, respectively. Piston **48** is further provided with a recess **50** in which is suitably secured an elastomeric medium **51**, such as rubber, vinyl chloride resin and the like, for working a flat sheet metal work piece **52** about the forming portion **41** of die **40**. As with the preceding embodiments of this invention, the explosive contained within cartridge **49** must be capable of driving piston **48** so that it, through the elastomeric medium **51**, exerts a pressure level within a maximum time interval of 10 milliseconds sufficient to force the work piece **52** into conformance with the forming portion **41**, of die **40**, at a velocity at least 10 feet per second.

Although the invention has been described with reference to specific embodiments, materials, and details, various modifications and changes, within the scope of this invention, will be apparent to one skilled in the art and are contemplated to be embraced within the invention.

What is claimed is:

1. A method for working metal with explosives comprising placing said metal adjacent a forming die having a configuration desired to be imparted to said metal, subjecting said metal to an explosive force, generated within a maximum time interval of 10 milliseconds to exert sufficient pressure transmitted to said metal to deform said metal under the impact of the applied force at a velocity at least 10 feet per second to 25 feet per second.

2. The method of claim 1 wherein said explosive force is transmitted to said metal through a hydraulic media.

3. The method of claim 2 wherein said velocity is 14 feet per second.

4. The method of claim 3 wherein said pressure is within the range of 500 to 75,000 pounds per square inch.

5. The method of claim 4 wherein said pressure is within the range of 1,000 to 10,000 pounds per square inch.

6. A method of working metal with explosives comprising positioning said metal within a combustion chamber containing a forming die, inserting in said combustion chamber an explosive charge capable of generating an explosive force sufficient to exert a pressure of 500 to 75,000 pounds per square inch transmitted to said metal within a maximum time interval of 5 milliseconds, said metal having a sufficient strength to restrain the velocity of deformation of said metal under the impact of said explosive force within the range of 10 to 25 feet per second, and igniting said explosive charge whereby the resultant force is transmitted to said metal to force it against the configuration of said die.

7. The method of claim 6 wherein the hydraulic media is interposed between said metal and said explosive force.

8. The method of working a metal tube with an explosive charge comprising placing said tube adjacent a forming die contained within a combustion chamber and having a configuration desired to be imparted to said tube, inserting in said combustion chamber an explosive charge capable of generating an explosive force within a maximum time interval of 10 milliseconds sufficient to exert a pressure on said tube to deform said metal tube under the impact of said explosive force at a deformation velocity within the range of 10 to 25 feet per second, igniting said explosive charge whereby the generated explosive force is transmitted to said metal tube to press it against the configuration of said die.

9. The method of claim 8 wherein a hydraulic media is interposed between said metal tube and said explosive force.

10. The method of claim 9 wherein said velocity is substantially 14 feet per second.

11. The method of claim 10 wherein the applied pressure is between 1,000 to 10,000 pounds per square inch.

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