

March 2, 1971

H. G. JOHNSON

3,566,650

DIAPHRAGM-TYPE SHEET FORMING METHOD

Filed April 10, 1969

5 Sheets-Sheet 1

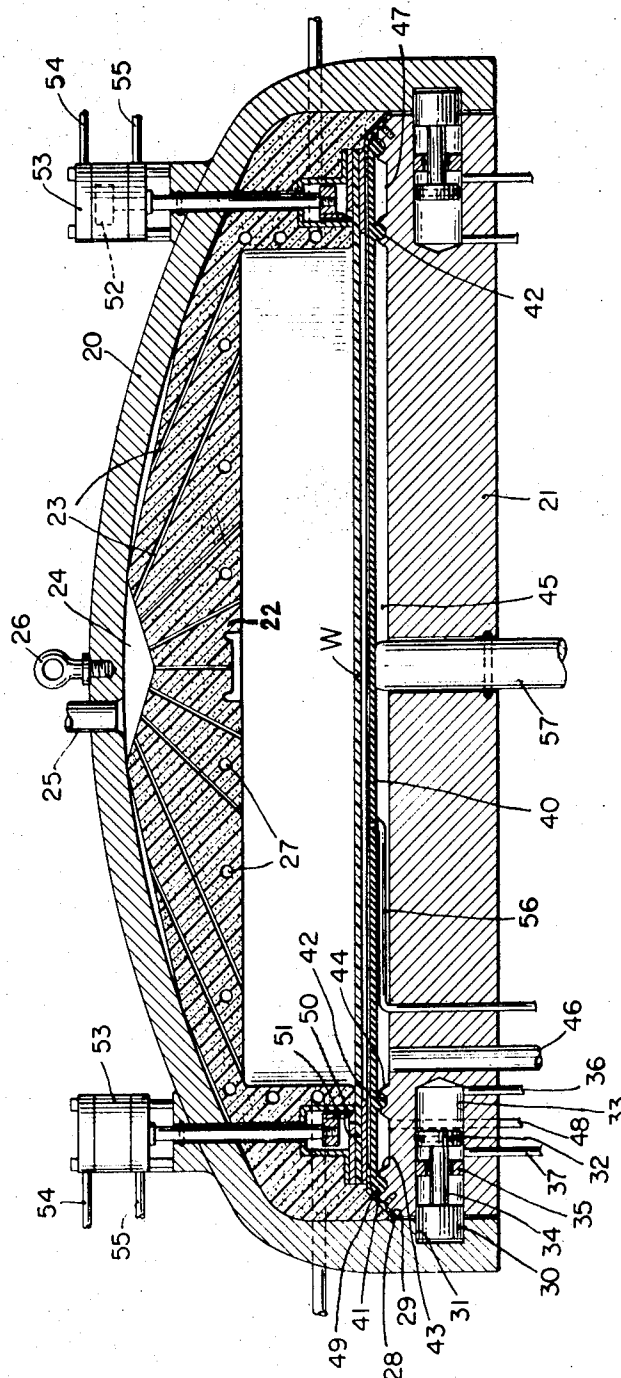


Fig. 1

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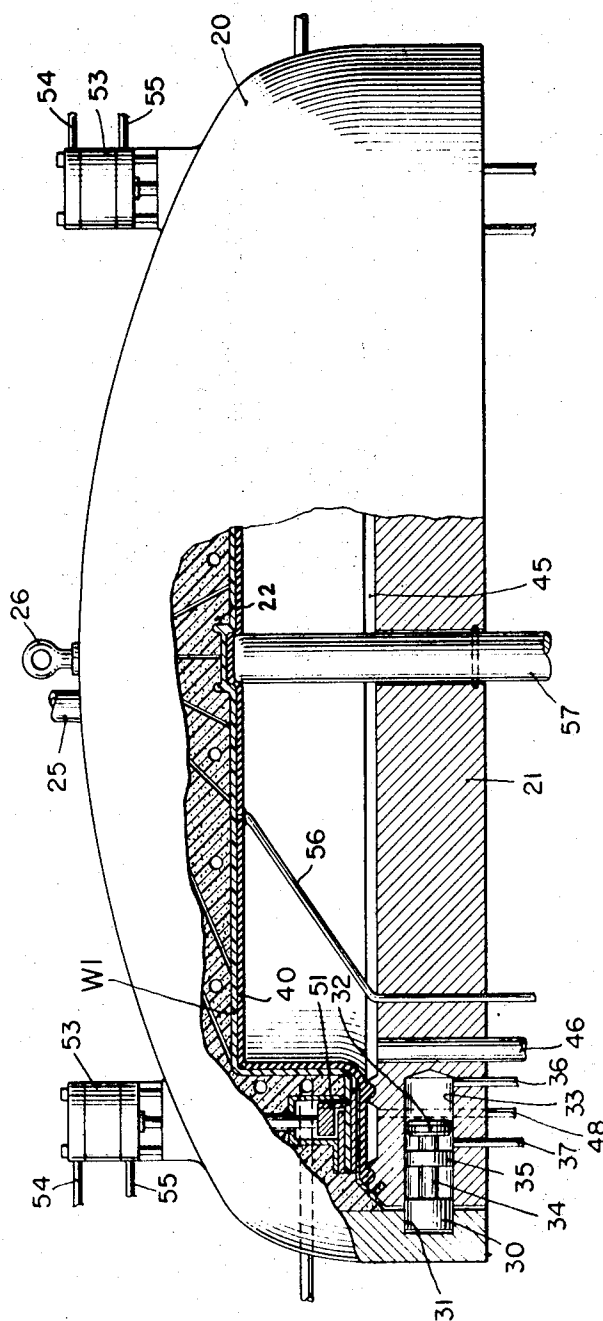
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DIAPHRAGM-TYPE SHEET FORMING METHOD

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5 Sheets-Sheet 2



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DIAPHRAGM-TYPE SHEET FORMING METHOD

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5 Sheets-Sheet 3

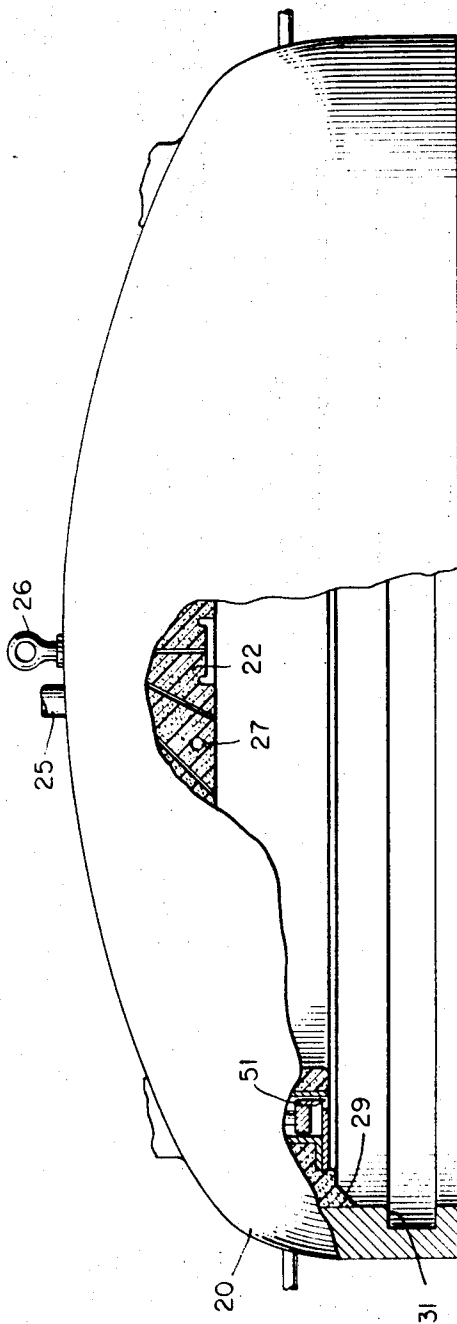
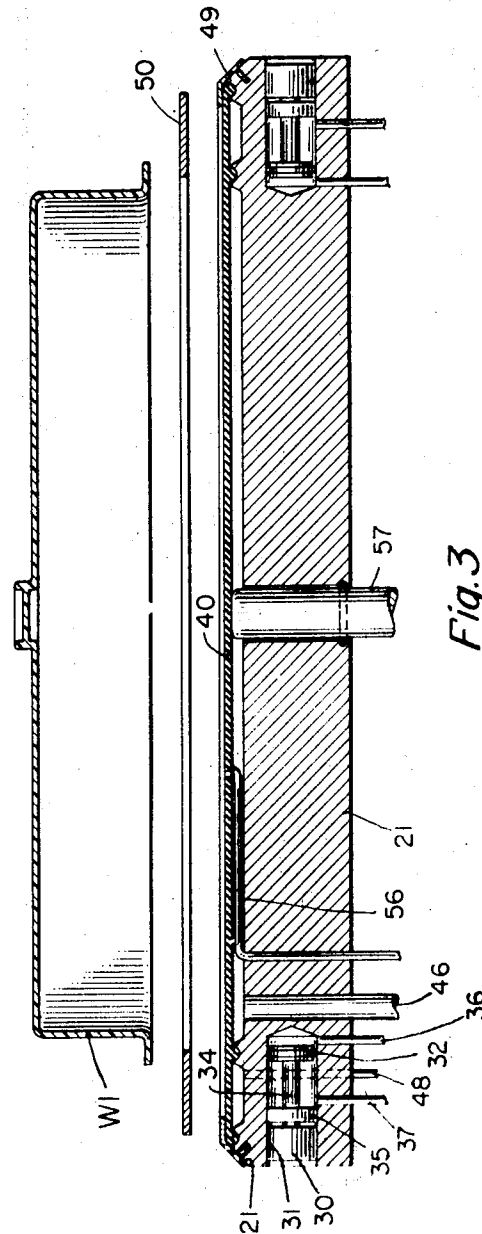


Fig. 3

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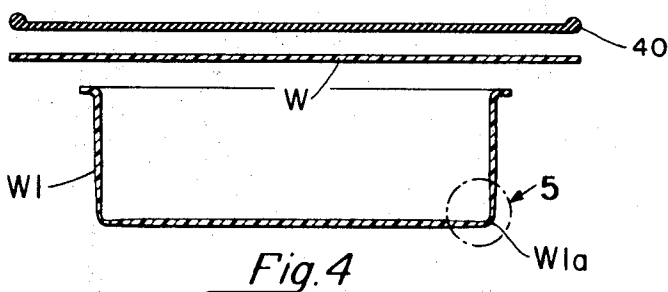
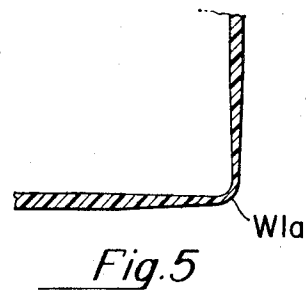
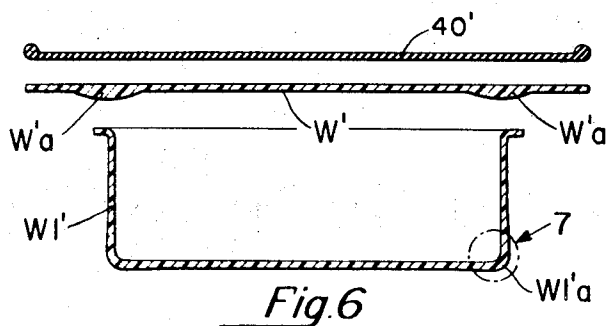
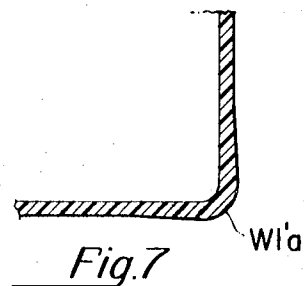
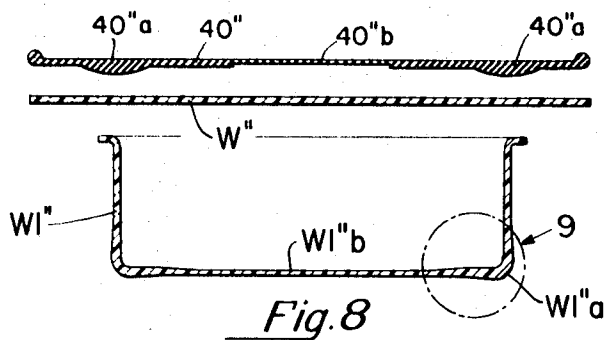
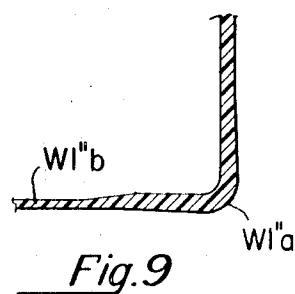
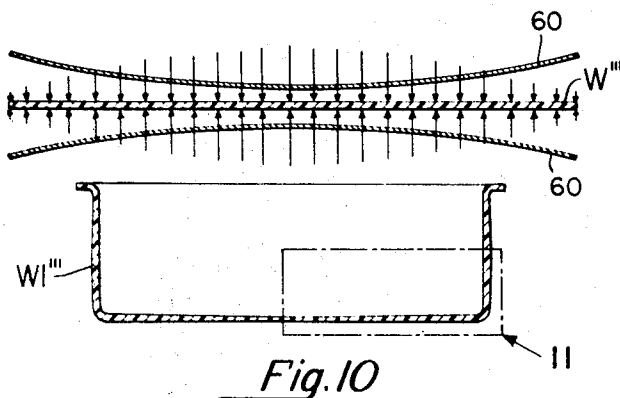
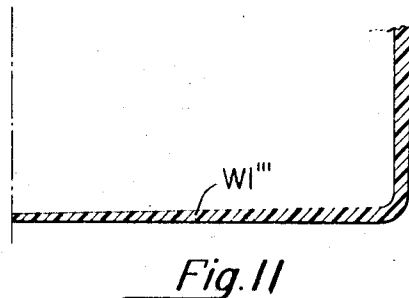
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DIAPHRAGM-TYPE SHEET FORMING METHOD

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5 Sheets-Sheet 4



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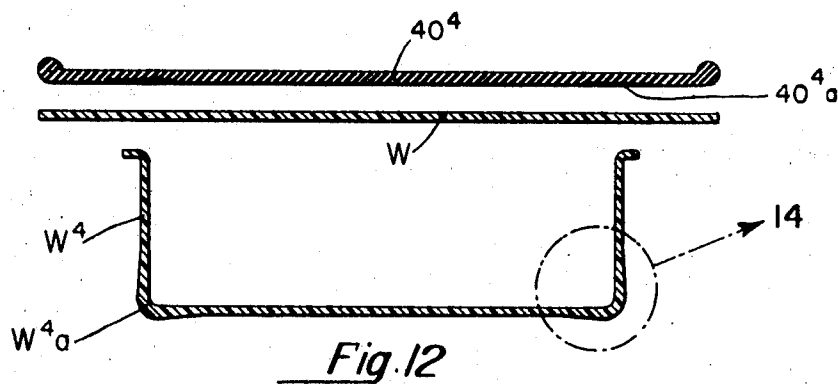
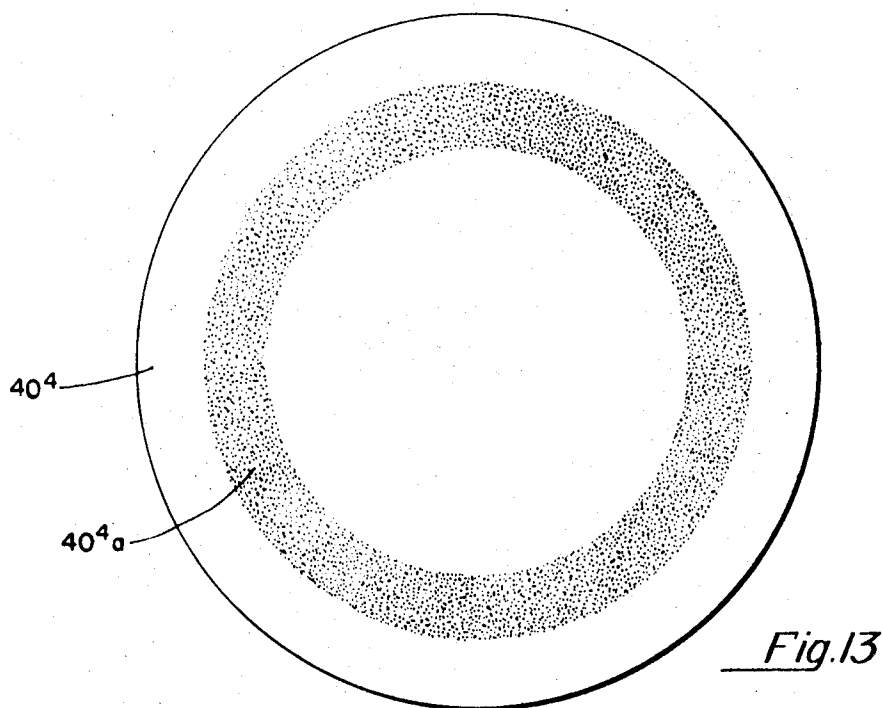
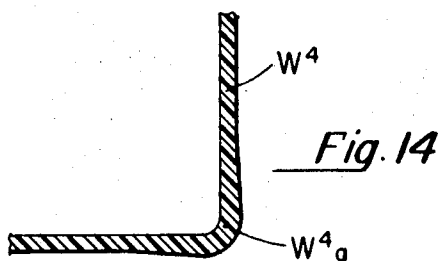
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DIAPHRAGM-TYPE SHEET FORMING METHOD

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5 Sheets-Sheet 5



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DIAPHRAGM-TYPE SHEET FORMING METHOD

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Continuation-in-part of application Ser. No. 660,491,
Aug. 14, 1967. This application Apr. 10, 1969,
Ser. No. 815,127

Int. Cl. B21d 22/12

U.S. Cl. 72—63

8 Claims

ABSTRACT OF THE DISCLOSURE

This application discloses diaphragm-type sheet forming apparatus and method for forming sheet blank workpiece material, especially plastic material, by such apparatus. The apparatus comprises a rigid die and an elastomeric diaphragm which is forced by fluid pressure into the die against a sheet workpiece blank to force the blank against the die to form a shaped article.

RELATED APPLICATIONS

This is a continuation-in-part of my copending application Ser. No. 660,491, filed Aug. 14, 1967.

BACKGROUND OF INVENTION

There have been proposals for forming articles by forcing a blank against a shaping die by fluid pressure and, in some cases, protecting the surface of the blank from direct contact by the fluid by a stretchable covering sheet.

When fluid pressure is applied directly to a blank, the variations in thickness or composition or physical defects inherent in commercially available sheet material tend to cause unequal and uncontrollable deformation, ballooning, splitting, and the like. The situation is not substantially improved when a mere covering sheet, having little or no required strength as compared to that of the blank, is used, as in known prior practice or suggestion.

In my copending application, Ser. No. 561,871, filed June 30, 1966, there is disclosed means and method for forming sheets of plastic materials within the "cold-forming" range by a deformable solid elastomer body which changes shape under compression in a fluid-like manner to force the blank into a die.

The use of a solid thick elastomeric pressure member against the blank gives some improvement but the flow of solid volumes of elastomeric material is not uniform like a true fluid and the shaping of blanks of certain shapes, as with sharp curvatures and substantial undercutting, is not as satisfactory as desired in most cases; and, moreover, the size and depth of draw by solid elastomer pressure members is quite limited. It is usual to exert pressure upon solid elastomeric shaping members by mechanical means to cause their deformation, rams, plungers, and presses being used, and this involves large and expensive equipment.

SUMMARY OF INVENTION

I have found that by avoiding the direct application of fluid pressure to a blank or using a mere cover protective sheet of little strength relative to the strength of the workpiece blank, and, instead, using an elastomeric sheet of very considerable strength relative to the strength of the workpiece blank sheet, using certain refinements in apparatus and operation, it is possible to avoid splitting, ballooning and non-uniformity of shaping and to improve the formation and shape-retention.

When a sheet-like strong elastomeric diaphragm is used it can conveniently be deformed by fluid pressure which is rapid in action and permits the elimination of large,

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expensive, and slow-acting power presses. Moreover, such diaphragm apparatus is almost unlimited as to the size of articles which it can produce.

The present invention provides strong diaphragm-type sheet forming apparatus which can be quickly brought into action on a sheet blank of different areas and thickness, and comprising single or plural laminae of the same or different materials and, in some cases, with metal laminae; which provides improved means for holding the blank; which provides convenient quick-acting means for securing and releasing the assembly parts; which provides means for controllably heating and cooling the blank and various areas of the blank; which provides means for selectively shaping different areas of the blank; which provides means for applying different pressures and different shaping elements to different areas of the blank; which provides means for performing separate secondary operations, such as punching or cutting portions from the finished workpiece article; which provides a method of forming a blank to obtain controlled local shaping, especially in the forming of plastics above their glass transition temperature—where they change from a brittle to a tenaciously stretchable condition and can be re-shaped, a point which is reported in technical literature for most plastics or can readily be determined.

The upper forming temperature limit is that at which the material loses coherency and tenacity and acts like a low viscosity liquid. The preferred range is that in which the material has adequate elongation to form the desired article without rupture. The diaphragm will support and preserve sheet coherency at temperatures above those which are permissible with other forms of sheet shaping equipment.

More commonly, thermoplastic polymeric materials are shaped according to this invention in their cold-working or solid-state working range, which is herein understood to be the temperature range above the polymer's glass transition temperature and below its thermoplastic temperature. In this range, the material is in work-strengthenable condition in which thinning due to stretching results in orientation and attendant strengthening of the thinned portion of the article. The term "thermoplastic temperature" is employed to refer to the crystalline melting point of crystalline polymers and, in the case of non-crystalline polymers, to the temperature at which the blank is softened enough to sag under its own weight, this being the temperature characteristically employed in conventional thermoforming methods such as vacuum forming.

It is also usually desirable to form many materials near but below their thermoplastic temperature, although as just stated, the diaphragm support will permit some materials, to be successfully shaped above their thermoplastic temperature if they retain sheet coherency and tenacity. The diaphragm supports such tender sheets and greatly minimizes rupture which would occur in many cases if the sheet blank were formed in mating dies or by directly-applied pressure fluid or by pressure fluid applied to a relatively weak stretchable cover sheet used merely for surface covering purposes. This is especially the case when the diaphragm is disposed horizontally; and more especially when it is disposed below the blank, as shown herein. Even blanks with holes or cut-outs can be formed with the strength diaphragm type of apparatus.

Some metals are also amenable to plastic stretch-forming, especially when sandwiched with stretch-formable polymer plastic laminae, one limitation being that the plastic laminae, if and when used with metal laminae, will not be injured and that the elastomeric diaphragm will not be injured when the metal laminae are heated to their shaping temperature. Normally, the shaping temperature of the plastic laminae will control when com-

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bined with metal laminae, the whole blank thickness, of course, being heated to the same temperature as a usual procedure, although it has been found feasible and convenient in some cases to heat one side of a relatively thick blank more or less than the other side.

The invention is particularly beneficial for sheet materials which have substantial spring-back after being shaped by usual means, the elastomeric diaphragm, as here used, substantially eliminating or killing the spring-back and greatly reducing the time for set after forming as compared to all-metal dies. It is especially useful for materials having substantial spring-back characteristics, such as polyethylene, polyvinyl chloride, cellulose acetobutyrate, polystyrene, acrylic polymers, polycarbonates, polypropylene, other polyolefins, cellulose esters, and the like, the principal one so far dealt with being polypropylene.

Sheet blanks, including laminated sheet blanks, may vary from very thin, say 0.01" or less, up to 1" or more, depending upon lateral area, pressure, depth of draw, and other factors.

Texturing of one or both surfaces of the article, locally or more extensively, is readily achieved by suitable mold die and diaphragm design. Deep drawing without wrinkling can be accomplished by separately controlling the forming and blank holding pressures.

The blanks commonly, and as illustrated, are planar but may be curved in one or more axes or even be in tubular form when it is desirable to make a number of articles from different sides of a tubular blank at one time or to make shaped tubular articles.

One of the objects of the invention is to provide a convenient and efficient method and apparatus for forming tenaciously stretchable sheet material, particularly plastic material, into useful articles up to large sizes with a minimum investment.

Another object is to provide method and means for deep-forming sheet material, of single or plural laminae, while keeping it free from wrinkles or undesired thinning and without requiring costly conventional press equipment or single purpose machines.

Another object is to provide simple but rapid method and means for converting sheets of thermoplastic polymers, having pronounced spring-back at temperatures above their glass transition temperature and below the temperature at which they lose their sheet coherency, into stable-shaped articles having dimensions which closely conform to those of the forming die.

Another object is to provide deeply-drawn or hollow articles from sheet plastic material having their designed wall thickness substantially maintained and their strength maintained or even increased in critical areas such as corners where the use of conventional methods and means would result in excessive thinning and resulting weakness.

Another object is to provide less costly and more efficient method and means than now available to produce articles in a wide range of sizes, shapes and thicknesses.

Another object is to provide means and method for performing one or more separate secondary operations on the workpiece while it is disposed in the diaphragm-shaping apparatus to save time and minimize equipment expense.

DRAWINGS

The above and other objects, as well as various advantages and features of novelty, will be apparent from the following description of an exemplary embodiment of the invention, reference being made to the accompanying drawings, wherein:

FIG. 1 is a central vertical section of axially symmetrical sheet-forming apparatus in closed position ready to form a workpiece sheet blank into an article;

FIG. 2 is a view like FIG. 1 but showing the parts after the article has been formed;

FIG. 3 is a view like FIG. 1 but showing the apparatus in open position with the article removed;

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FIG. 4 is a section of a sheet blank and article formed therefrom by press means and method with blank diaphragm of uniform thickness;

FIG. 5 is an enlarged partial section taken in the circled zone of FIG. 4;

FIG. 6 is a section of a plain uniform thickness diaphragm and a pre-shaped blank and the article formed from the blank according to the present invention;

FIG. 7 is an enlarged partial section taken in the circled zone of FIG. 6;

FIG. 8 is a section of a shaped diaphragm and a plain blank and the article formed from the blank according to another mode of the present invention;

FIG. 9 is an enlarged partial section taken in the circled zone of FIG. 8;

FIG. 10 is a section of a preheated blank and one form of heating means for producing differential area thinning of the article;

FIG. 11 is an enlarged partial section taken on the right side of FIG. 10;

FIG. 12 is a section of a friction-differential diaphragm and a plain blank and the article formed from the blank according to another mode of the invention;

FIG. 13 is a plan view of the diaphragm as seen from the friction-differential side;

FIG. 14 is an enlarged partial section taken on the circled zone of FIG. 12.

DESCRIPTION OF PREFERRED EMBODIMENT

The apparatus provided by the present invention is essentially self-contained in that the external equipment needed is auxiliary only, such as hoist, pressure fluid supply means, vacuum producing system, and heating and cooling fluid supply means, all of which are usually available for general purpose use in any well-equipped plant or shop. The apparatus can occupy a fixed location and have suitable fluid conduit connections and pressure and temperature flow and control means, together with such electrical wiring and connections and controls as may be needed for full effective operation in the chosen location. Such service equipment is so well known that it should be sufficient to note that it is understood to be supplied without specifically illustrating it.

A strong pressure enclosure is provided by a die housing 20 and rigid reaction means, such as a closure base 21. The housing 20 is preferably dome-shaped to provide maximum strength for thickness of material, steel being the usual material used for the housing and base.

Within the housing 20 there is disposed a shaping die 22 which may be of a strong ceramic mold material of known type, such as fused silica, which is cast, poured or injected into the housing and shaped interiorly by a form pattern or shaping tools or both.

It is important to evacuate the space between the die and blank to permit accurate formation of the article and this can conveniently be achieved by using a known porous structure, such as that known as "Glasrock" open cell fused silica foam, to form the die. The small irregular porosity of this type of material cannot well be illustrated, so alternative means is here represented by small ducts 23 extending from the die cavity to a header space 24 served by a vacuum and pressure pipe 25 having suitable flow, pressure, and temperature control means associated therewith. There could be separate vacuum and pressure pipes, depending upon available auxiliary equipment. A lift eyebolt 26 is provided on the housing 20.

The porous cell openings or passages in the die are so small that the surface of the formed article will not be noticeably marred or forced into the cavities. Materials are available with various desired sizes of porosity. Pressure between the die and article after formation is important in removing the formed article from the die without damage.

Cooling or heating means, including cast-in tubes 27 or electrical heating elements, together with suitable flow,

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pressure, and temperature control means, are provided for the die. One system is shown but there may be a plurality of systems for separately cooling and heating the whole die or several local portions separately to provide differential area heating or cooling, if desired.

The closure base 21 is generally flat in shape and fits at the edge within the housing 20. It has a bevelled portion 28 which accurately fits within a bevelled socket seat 29 in the upper part of the assembly, here in the die part 22. This provides accurate registry when the upper and lower parts are brought together.

Means of a quick-acting nature are provided for locking the parts 20, 21 together and quickly releasing them for separation, the means here shown comprising a plurality of plungers or bolts 30 carried by one member which enter sockets 31 in the other member. Cylindrical plungers are shown for simplicity but they may be arcuate segments engaging the annular groove shown for greater surface engagement and retention strength. Conveniently the plungers may be actuated each by a piston 32 operating in a cylinder 33, the cylinder having a rod 34 passing through a sealed bore in a head 35 firmly secured in the cylinder bore. Operating fluid is supplied by pipes 36, 37 having suitable flow control means. Two such power devices are shown but there may be as many as desired, preferably in opposed pairs and all provided with fluid supply and exhaust means, preferably from a common source so they will all be operated together.

A strong elastomeric pressure diaphragm 40 is secured above the lower member 21, here having radially spaced circumferential enlargements 41, 42 fitting in grooves in annular raised ribs 43, 44 on the member 21. The main pressure fluid chamber 45 below the diaphragm is preferably shallow, as shown, and provided with a pressure fluid supply and exhaust pipe 46 having suitable flow, pressure, and temperature control means.

It is to be noted that the diaphragm is disposed in a horizontal position and, especially, that is disposed below the position to be occupied by the blank so as to fully support and back workpiece blank sheets without rupture even though they may be very thin and tender or have portions of different thickness or even have cut-out portions since the blank sheet is not required to take fluid pressure or shaping die contact directly on its back. It is to be understood, however, that the diaphragm may be disposed above the blank or that dispositions other than horizontal may be used.

An outer clamping chamber 47 is provided between the enlargements 41, 42 of the diaphragm, this chamber being provided with a pressure fluid supply and exhaust pipe 48 having suitable flow, pressure, and temperature control means. The diaphragm is held at its outer edge, as by a retaining ring 49.

An annular removable clamping ring 50 is provided above the outer peripheral portion of the diaphragm 40 spanning the clamping chamber 47; and the workpiece, here a flat sheet blank W, is secured between the clamping ring 50 and the upper assembly, here against a flat surface of the die, pressure on the outer portion or periphery of the diaphragm, applied by fluid in the clamping chamber 47, determining the holding grip applied to the outer edges of the blank.

After the workpiece article W1 has been formed, or even while it is being formed, its rim may be given an auxiliary or secondary operation of punching, cutting, or the like, here, as illustrated, having the outer portion cropped or trimmed off by an annular blade 51 operated by power means such as pistons 52 in cylinders 53 having fluid supply and exhaust pipes 54, 55 with suitable flow control means. The blade 51 acts against the rigid metal clamping ring 50, the temperature being controlled in this region, as partly by the temperature of the clamping pressure fluid.

The diaphragm tends to adhere to certain blank materials and it is difficult to separate the workpiece from the

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diaphragm without injury to the workpiece or diaphragm or both by mechanical means. To facilitate such separation, as well as to exhaust fluid from the space between workpiece and diaphragm, the diaphragm is provided with a fluid supply and exhaust tube 56 of elastic material secured at its end in the diaphragm, as by vulcanization. The fluid is of controlled flow, pressure, and temperature and may have controlled lubricity (interfriction between diaphragm and workpiece) properties to assist in controlling the forming action.

If special shaping of portions of the workpiece is desired, this may be provided by applying final increased and concentrated pressure where desired, either by a metal plunger acting directly on the blank and sealed in the diaphragm or by acting through the diaphragm, as shown for plunger 57 having separate power actuating means.

The diaphragm is made of strong elastomeric material, such as rubber, neoprene, or the like, and it has been found that such material exerts a strong lateral drag on the workpiece material. This is illustrated in FIGS. 4 and 5 where a plain sheet workpiece blank W of uniform thickness is shaped by a diaphragm 40 to form a cup-shaped workpiece article W1. At the bottom corner of sharp curvature where the diaphragm is most stretched and thinned, the article is also substantially thinned, as indicated in exaggerated scale at W1a; in the case of articles made from crystalline polymer compositions, such as high density polypropylene or polyethylene, such thinning results in desirable work strengthening of the thinned area by orientation.

The present invention takes account of this effect and turns it to advantage for differential area drawing. This may be done in several ways: as (1) by locally altering the thickness of the workpiece blank or even by having cut-out portions, this being feasible where the forming body is continuous, here the diaphragm which takes the fluid pressure; (2) by locally altering the thickness of the diaphragm; (3) by locally altering the thickness of both blank and diaphragm; (4) by locally altering the temperature of the blank as supplied or by local control of die or diaphragm temperature during formation of the article; (5) by locally controlling the relative coefficient of surface friction between diaphragm and blank by diaphragm or blank surface texture or by locally supplied fluid characteristics, either of a friction reducing or friction increasing nature.

FIGS. 6 and 7 illustrate how a blank W' may be thickened, as at W'a, to reduce stretch locally, with a diaphragm 40 of uniform thickness, to form an article W1' with a corner W1'a which is thicker relative to adjacent portions.

FIGS. 8 and 9 illustrate how a diaphragm 40'' may be thickened, as at 40''a, and thinned, as at 40''b, to act upon a blank W of uniform thickness to form a workpiece article W1'' having a thickened corner W1''a and a thinned bottom W1''b.

FIGS. 10 and 11 illustrate how a blank W''' may be differentially preheated, as by curved heating plates 60, 60 (exaggerated in curvature for illustrative emphasis), whereby to form an article W1''' which varies in thickness from bottom center to the top outer edge.

FIGS. 12-14 illustrate how a diaphragm 40⁴ may be provided with a local zone 40⁴a of a differential frictional character, here a single circumferential zone and of greater frictional coefficient than the adjacent inner and outer zones, to act upon a blank W of uniform thickness to form a workpiece W⁴ having a thickened bottom corner W⁴a. Inserts of different materials of different friction coefficient may be locally incorporated in the die or diaphragm or even in the workpiece blank to achieve differential area stretch effects.

Overall thinning control of the blank can be achieved by varying the blank-holding pressure on the periphery

of the blank to regulate the amount of material which is drawn in from the periphery of the blank, at the same time obviating wrinkles.

The use of a rubber diaphragm assists in the formation of undercut portions on articles, the diaphragm readily moving out in all directions when fluid pressure is applied and being readily drawn out of such undercut portions, and the formed article being readily extractible in many cases without divided die formations, especially if the workpiece is thin and of a flexible nature.

As brought out above, the present improvement makes advantageous use of the joint compression and lateral stretch of a diaphragm forming element, using the novel apparatus and method in a manner to attain new and very beneficial results.

In addition to certain metals and other materials which can advantageously be formed in accordance with the present invention, the following plastics have been formed or appear suitable for forming in accordance with the present invention: polypropylene, polyethylene, polyvinyl chloride, polyvinylidene chloride, acrylonitrile-butadiene-styrene, polyamide, polystyrene, fluorocarbon polymers, acrylic polymer, cellulose acetate, cellulose butyrate, cellulose nitrate, polyether, ionomers, polycarbonate, polyester, polyphenylene oxide, polysulfone, polyurethane, and possibly others which have not yet been investigated.

As stated, the sheet blank may comprise one or a plurality of laminae of the same or different materials, and may have plastic and metal laminae combined in various ways.

While practicing the invention, it was discovered that certain unique and useful articles could be formed which, as far as is known, no alternative method of manufacture is practicable. One such class of articles is characterized as having permeable walls of porous open-cell or perforated plastic, or other stretchable sheet material. Another class of articles is further characterized as having multi-ply walls of desired color, composition, thickness, temperature, melting point, or other physical and chemical properties. Such articles, obviously, cannot be produced by conventional melt-phase practices, such as injection-molding, rotational-molding, vacuum-forming, blow-molding, casting, extruding, or mating-die forming. These materials are readily diaphragm-fluid-pressure-formed into hollow shapes in accordance with the present invention without losing their desired characteristics or being excessively thinned, torn, or otherwise damaged during processing.

Suitable working temperatures are readily determined for each work-material. Illustrative of those considered most suitable for working prevalingly isotactic polypropylene, which are in the range from about 150° F. to just below the crystal melting point of 335° F., a preferred range being between about 300° F. and about 330° F. These temperatures are in the cold-working range in which isotactic polypropylene is work-strengthenable.

Unless deliberate temperature variation is utilized, the blank is preferably heated to a substantially uniform temperature, e.g., not varying by more than 2° F. from the desired value across the surface of the blank. Suitable heating means are contact heaters, e.g., hot plates, or radiant heaters.

Working pressures will range from about 100 to 500 p.s.i. or more, depending on the kind, thickness, and temperature of the blank material. A holding time of about 1 to 15 seconds is usually sufficient to set material to shape to avoid spring-back.

The fluid applied to the diaphragm may be gaseous, as air or liquid, as water; liquid being particularly effective in forcing the diaphragm and workpiece material into small spaces and sharp bends; or liquid assisted by gaseous fluid pressure or by mechanical means will have ad-

vantages for some purposes. Mechanical assistance is herein exemplified by the plunger 57.

It is thus seen that the invention provides new and useful means and method for forming tenaciously stretchable materials, especially plastic polymer materials, in an expeditious and economical manner.

While certain embodiments of the invention have been described for purposes of illustration, it is to be understood that there may be various other embodiments and modifications within the general scope of the invention.

I claim:

1. The method of forming articles from stretchable sheet blank workpiece material, including weak and fluid-permeable sheet blanks, which comprises, positioning a workpiece sheet blank at shape-retaining stretchable temperature between a rigid shape-imparting die member having a shape-imparting area and an edge-clamping peripheral area and a strong fluid-impervious elastically deformable diaphragm means having separately deformable areas overlying the shape-imparting area and the clamping peripheral area respectively of said die member, applying fluid at controlled pressure to the diaphragm means in said edge-clamping peripheral area to clamp the periphery of the workpiece sheet blank securely against pull-in, thereafter applying fluid at controlled pressure to the shape-imparting area of the diaphragm means to shape the workpiece sheet blank, relieving the forming pressure after the formed article has taken a shaped set in the die, and thereafter relieving the clamping pressure and removing the formed article.

2. The method as set forth in claim 1, which further comprises, pressing the periphery of the sheet blank by a clamping ring acted upon by the edge-clamping peripheral area of said clamping means.

3. The method as set forth in claim 2, which further comprises, performing an operation on the blank periphery against the clamping ring.

4. The method as set forth in claim 3, in which said operation includes severing a portion of the periphery from the body of the formed article.

5. The method of forming articles from stretchable sheet blank workpiece material, including weak and fluid-permeable sheet blanks, which comprises, positioning a workpiece sheet blank at shape-retaining stretchable temperature between a rigid shape-imparting die member and a strong fluid-impervious elastically deformable diaphragm, the blank and diaphragm having localized interior areas of differential surface stretch characteristics relative to other areas, clamping the periphery of the blank and diaphragm securely against edge pull-in, subsequently applying fluid at controlled pressure to the diaphragm to act upon the blank and shape various areas differentially according to different local surface stretch area characteristics between the blank and diaphragm, relieving the forming pressure after the formed article has taken a shaped set in the die, and thereafter relieving the pressure fluid and removing the article.

6. The method as set forth in claim 5, in which the differential local area stretchability is provided by using a diaphragm and blank having local areas of different thickness relative to each other and relative to other adjacent local areas, the thicker areas stretching less laterally and thinning the blank less than the thinner areas during formation.

7. The method as set forth in claim 5, in which the differential local area stretchability is provided by using a blank having local adjacent areas of different temperature relative to other adjacent local areas.

8. The method as set forth in claim 5, in which the differential local area stretchability is provided by using a diaphragm and blank having local areas of different surface coefficient of friction relative to each other and relative to other adjacent local areas.

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18—19; 29—421; 264—89