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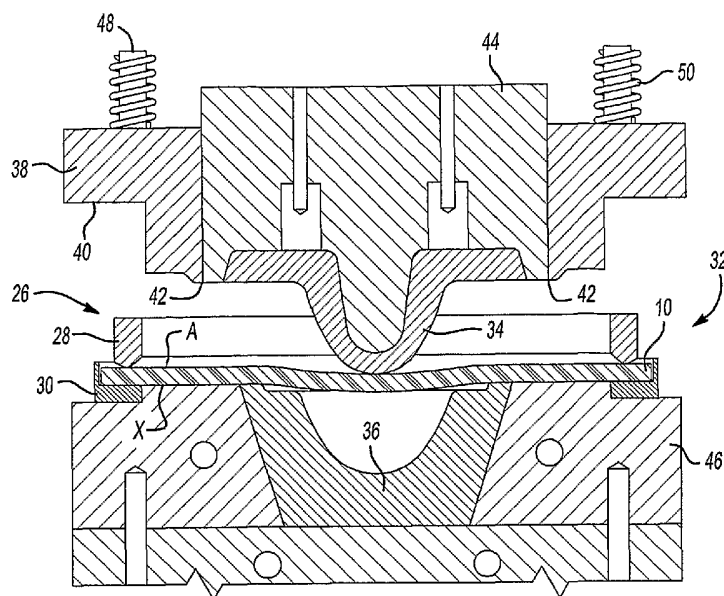
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[Continued on next page]

(54) Title: APPARATUS AND PROCESS FOR MANUFACTURING SHAPED PLASTIC REINFORCED COMPOSITE ARTICLES



(57) Abstract: A process for forming a shaped three dimensional article, comprising the steps of deforming an intermediate form (10), including a plurality of thermoplastic elongated members that are initially movable relative to each other, while displaceably clamping the intermediate form during the deforming in such a way that while a force is applied for deforming the intermediate form, the intermediate form is free to move within a predetermined limit; and optionally at least partially consolidating the thermoplastic elongated members of the intermediate form for forming a three dimensional article having a predetermined orientation of the elongated members. An apparatus including a press (32) for forming the shaped three-dimensional article is also disclosed.

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APPARATUS AND PROCESS FOR MANUFACTURING SHAPED PLASTIC REINFORCED COMPOSITE ARTICLES

CLAIM OF PRIORITY

[0001] The present application claims priority to, and the benefit of the filing date of, United States Provisional Application Nos. 60/621,463 filed on October 22, 2004 (Attorney Docket No. 63863; 1062-041P1); 60/717,965 filed on September 16, 2005 (Attorney Docket No. 63863B; 1062-041P2); 60/718,025 filed on September 16, 2005 (Attorney Docket No. 64371; 1062-051P1); and 60/725,399 filed on October 11, 2005 (Attorney Docket No. 63863C; 1062-041P3), (Express Mail No. EV789808245US), all of which are incorporated by reference.

CROSS-REFERENCE TO RELATED APPLICATIONS

[0002] The present application is related to concurrently filed, commonly owned, copending application entitled Improved Polyolefinic Materials For Plastic Composites (Attorney Docket No. 63863D; 1062-41WO1); Plastic Composite Articles and Methods of Making Same (Attorney Docket No. 63863E; 1062-41WO2); Improved Microlayer Structures and Methods (Attorney Docket No. 63863F; 1062-41WO3); and Improved Composite Pipes and Method of Making Same (Attorney Docket No. 63863G; 1062-41WO4); all of which are incorporated by reference.

TECHNICAL FIELD

[0003] The present invention relates to the manufacture of shaped plastic composite articles, and particularly three-dimensional shaped plastic composite articles that incorporate an intermediate form that consists essentially of thermoplastic elongated members.

BACKGROUND OF THE INVENTION

[0004] In the shaping of plastic articles from a substantially flat sheet of plastic, such as by vacuum forming, or thermoforming it is often desired but

difficult to control wall thickness throughout the resulting formed article, particularly as a result of unbalanced flow within the sheet.

[0005] In the shaping of three-dimensional articles made from intermediate forms having repeating structural units, such as a fabric woven from plastic tape, the potential for wall thickness variations is further heightened. In particular the ability, in unconsolidated forms such as fabrics woven from a plastic tape, to control the desired resulting wall thicknesses is complicated not only by the possibility of local thinning of individual tapes, but also from the ability of adjoining tapes to move relative to each other during deformation and result in uncontrollable tape spacing that would affect resulting surface finish, properties or both in the shaped article.

[0006] One object of the invention is to provide a mechanism and process for retaining an intermediate form (particularly one that includes a plurality of elongated members) so that controlled deformation of the form occurs upon application of a pressure to it.

SUMMARY OF THE INVENTION

[0007] The present invention relates to a process for forming a shaped three dimensional article, comprising the steps of deforming an intermediate form, including a plurality of thermoplastic elongated members that are initially movable relative to each other, while displaceably clamping the intermediate form during the deforming (i.e., clamping the intermediate form in such a way that while a force is applied for deforming the intermediate form, the intermediate form is free to move within a predetermined limit (for example, lateral slippage of a distance up to about 20%, 40%, 60% or higher of the total draw depth of the deformed intermediate form) relative to the structure that performs the clamping function); and at least partially consolidating the thermoplastic elongated members of the intermediate form for forming a three dimensional article having a predetermined orientation of the elongated members. The invention also relates to an apparatus for forming a shaped three dimensional article that is configured to permit displacement (e.g., lateral slippage) of the intermediate form during deforming.

The process and apparatus of the present invention provides a unique approach toward balancing flow within a plastic intermediate form, especially forms that are made from thermoplastic tapes.

DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1A is a plan view illustrating a device for shaping an intermediate form.

[0009] FIGS. 1B-1D illustrate steps that employ the device of FIG. 1A.

[00010] FIG. 1E is another approach to a device for shaping the intermediate form.

[00011] FIG. 2 is a perspective view of an example of a mounting frame useful in the present invention.

[0011] FIGS. 3A and 3B are side sectional views through a tooling assembly useful in accordance with the present invention, respectively in the open starting position and during a deforming operation.

[0012] FIGS. 4A and 4B are side sectional views through an optional secondary tooling assembly useful in accordance with the present invention, respectively in the open starting position and during a secondary deforming operation.

[0013] FIG. 5 is a perspective view of an example of an apparatus for carrying tooling assemblies in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0014] The present invention is predicated upon the discovery of a unique approach to the manufacture of three dimensional articles, and particularly three dimensional intermediate forms that are at least partially consolidated for fabricating an article, such as one adapted for incorporation into a shaped composite that includes the intermediate form as a polymeric (and more particularly a thermoplastic polymeric) reinforcement material. The present invention, though in one aspect it contemplates improved manufacturing processes, also contemplates articles produced by the process, and machines

useful in the process. Articles having relatively complex geometries may be successfully made in accordance with the present teachings, such as articles requiring a relatively deep draw, as well as articles that have rounded or even square or other sharp corners.

[0015] In general, the present invention addresses important needs in the art by providing a process including the basic steps of shaping and consolidating an intermediate form that includes a plurality of aggregated elongated members (particularly ones that consist essentially of a thermoplastic material). As will be appreciated with reference to Serial No. 60/621,463, entitled: "PLASTIC REINFORCED COMPOSITES", filed October 22, 2004 (Attorney Docket No. 63863; 1062-041P1) (incorporated by reference herein), and U.S. Provisional Application Serial No. 60/717,965, filed September 16, 2005 (Attorney Docket No. 63863B; 1062-041P2), entitled: "PLASTIC REINFORCED COMPOSITES" (incorporated by reference herein) and U.S. Provisional Application Serial No. 60/725,399 (Attorney Docket No. 63863C; 1062-041P3), by "elongated member", it is generally meant a member that has one of its dimensions (e.g., length) that is longer than at least one other dimension (e.g., width, height, thickness, or diameter), particularly, the length of an elongated member here in substantially greater (e.g., by a factor of at least 10 or higher) than the width or height. Accordingly, elongated members herein could include, but are not necessarily limited to a member selected from fibres, rods, cords, yarns, tapes, filaments, straps or any combination thereof. As can be appreciated from the above, in a number of aspects, films may also be contemplated as within the meaning of "elongated members". Small scale members may also be possible, such as whiskers or platelets. Though "elongated member" is regarded broadly herein, it should be recognized that particularly preferred forms of the elongated member specifically will include one or more of yarns, tapes, fibres and filaments. A highly preferred elongated member is in the form of a tape.

[0016] In addition, it should be appreciated that elongated members of the present invention typically will have been processed for achieving an initial morphology, and specifically an initial orientation state (e.g., it is monoaxially

stretched, biaxially stretched, or otherwise stretched, such as in accordance with the proportions specified herein). Among the many unique advantages obtainable using the subject matter disclosed herein is the ability upon conclusion of processing, and especially in finished articles, to realize a substantial preservation of the initial morphology within the elongated member. Accordingly, for example, upon processing, molecular orientation of the elongated member is substantially preserved from its initial state (e.g., at least about 75 % of the initial orientation of the elongated member remains).

[0017] Accordingly, elongated members herein could include, but are not necessarily limited to a member selected from fibres, rods, cords, yarns, tapes, filaments, straps or any combination thereof. Small scale members may also be possible, such as whiskers or platelets. At least partially along the length of the elongated members, the members could be fully densified, partially densified (e.g., foamed), perforated, corrugated, twisted, or any combination thereof.

[0018] The dimensions of the elongated member typically could be such that it enables the member to be handled manually. More particularly, however, the elongated member will be dimensioned so that it is capable of being machine-handled for processing it into the intermediate form. For example, one specific illustration of the present invention envisions an elongated member, such as a yarn, tape, fibre or filament, that has a thickness, width or both no larger than about 1 cm, more specifically no larger than about 0.5 cm, and even more specifically no larger than about 1 mm. For example, one approach is to employ an elongated member such as a yarn, tape, fibre or filament that has a width of less than 5 mm, and a thickness of less than 1 mm and more specifically less than 0.5 mm (e.g., about 0.01 to 0.25 mm).

[0019] The elongated member may be a monolithic. It may be a single material, a multi-layer material or a combination thereof. A typical geophysical textile manufactured from polypropylene tapes would be an example of a fabric woven from such elongated members. The elongated member may have properties or other characteristics that differ along a dimension of the member. In one aspect, the elongated member may include a first surface portion and a

second portion that adjoins the first portion, wherein the first portion and the second portion differ in composition, polydispersity, morphology (e.g., crystallinity, orientation or both), melt rate, or any combination thereof. For example, one specific approach envisions at least one elongated member of a first thermoplastic material and having a surface portion capable of melting prior to an adjoining oriented portion.

[0020] As discussed in Serial No. 60/621,463, entitled: "PLASTIC REINFORCED COMPOSITES", filed October 22, 2005 (Attorney Docket No. 63863; 1062-041P1) (incorporated by reference herein), and U.S. Provisional Application Serial No. 60/717,965 filed September 16, 2005 (Attorney Docket No. 63863B; 1062-041P2), entitled: "PLASTIC REINFORCED COMPOSITES" (incorporated by reference herein), and U.S. Provisional Application Serial No. 60/725,399 (Attorney Docket No. 63863C; 1062-041P3), at least one elongated member is processed to make an intermediate form, such as an intermediate form selected from a winding form, a knit form, a braided form, a randomly dispersed form or any combination thereof. As referenced herein the intermediate form will typically include a plurality of repeating structural units. For example, an intermediate form might include a plurality of repeating structural units arranged to define a pattern, such as a plain or a twill weave (such as a herringbone, a tweed, a houndstooth, a plaid or other twill), a lace, a satin, or any combination thereof. Examples of particular weaves include weaves that having a pattern warp elongated member running over and then under a weft elongated member in a warp/weft proportion ranging from 1/1 to 14/2 (e.g., 2/1, 2/2, 3/1, or otherwise). Thus, still more particular examples of weaves include, without limitation, a 2/1 twill, a 2/2 twill, a crowfoot satin, a 2/2 basketweave, a 5H satin, a 8-H satin, or otherwise. Individual structural units of the form may be disposed in any of a number of possible configurations relative to each other. For example, overlapping units may be generally perpendicular to each other. However, other angles of weave may also be employed as desired. One attractive benefit obtainable in accordance with the present invention is that the intermediate form

can be processed so that the resulting shaped article generally retains the orientation of the repeating structural units relative to each other.

[0021] Prior to any step of shaping, typically, adjoining structural units are movable relative to each other within an intermediate form. One approach to achieving this is to form the intermediate form, but not subject it to a consolidating processing step by which adjoining structural units will become irreversibly joined together, such as by gluing, melting, fastening or otherwise assembling the units. Accordingly, at a time prior to commencement of deforming in accordance with the process steps of the present invention, it is particularly desirable the intermediate form not be consolidated, such as by heating to a temperature above the melting point of at least one of the materials in the form to cause the material to melt and fuse, and effectively weld with adjoining units.

[0022] Intermediate forms may include or consist essentially of a single layer (which optionally may include one or a plurality of patterns). An intermediate form that includes a plurality of layers (which optionally may include one or a plurality of patterns) over some or all of their respective surfaces, is also contemplated. For example, the number of layers in the intermediate form may range from about 1 to 100 or more (e.g., 2 to 60, 5 to 50, 10 to 40, greater than 10, greater than 20 or otherwise). Accordingly, it is envisioned that the intermediate form, in an unconsolidated state may have a thickness as small as the thickness of a single elongated member in it, but may be greater, such as on the order of about 0.25 mm. to about 2.5 cm or larger. In the consolidated state, accordingly, it is envisioned that the intermediate form may result in a thickness of about 0.8 mm or smaller to about 1.5 cm or larger, for example about 0.1 to 0.8 cm or more specifically about 0.3 to 0.5 cm.

[0023] If a plurality of layers is employed, it is possible that one or more layers are different from each other in one or more respect, such as material type, composition of the elongated member, heat treatment of the elongated member, width of the elongated member, pattern type, whether the layer is consolidated or not, the presence of a film layer, thickness, morphology, or any combination thereof. To illustrate, it is possible that at least one first layer selected from a film,

a coating (e.g., a solvent coating, an extrusion coating or otherwise), a intermediate form, a winding form, a knit form, a braided form, a randomly dispersed form or any combination thereof adjoins at least one second layer selected from a film, a coating (e.g., a solvent coating, an extrusion coating or otherwise), an intermediate form, a winding form, a knit form, a braided form, a foam form, a randomly dispersed form or any combination. As indicated, at least one of the plurality of layers may be consolidated in this illustration. It may also be possible that a charge of flowable unformed or formed (reinforced or unreinforced) plastic material may be placed over the exterior of the intermediate form or between adjoining layers, whether over the entire area of the form or a pre-selected portion of it. In this regard, it is possible to realize a flowable phase that can locally be fully densified, without the need for a complete layer to be employed in that vicinity. It will also be appreciated from the above that portions of one or more of the layers can be selectively omitted or otherwise modified so that variations in wall thickness are achieved or local regions of the article are selectively modified.

[0024] Ordinarily, the elongated members will be a polymeric material and particularly a thermoplastic material. One particularly preferred class of thermoplastic materials will include at least one polyolefin (e.g, polypropylene, or propylene-ethylene copolymers), such as a polyolefin available from The Dow Chemical Company under, for instance, the designations VERSIFY™ or INSPIRE®. Additional examples of material suitable for the elongated members are disclosed in Serial No. 60/621,463, entitled: "PLASTIC REINFORCED COMPOSITES", filed October 22, 2004 (Attorney Docket No. 63863; 1062-041P1) (incorporated by reference herein), and U.S. Provisional Application Serial No. 60/717,965, filed September 16, 2005 (Attorney Docket No. 63863B; 1062-041P2), entitled: "PLASTIC REINFORCED COMPOSITES" (incorporated by reference herein), and U.S. Provisional Application Serial No. 60/725,399 (Attorney Docket No. 63863C; 1062-041P3).

[0025] The polymeric material of the elongated members may be a homopolymer, a copolymer, a blend or some other admixture of polymers. For

example, a polypropylene homopolymer may be employed. Alternatively, or in addition to the polypropylene homopolymer, an example of a copolymer include two or more different polyolefins, e.g., a polypropylene/polyethylene copolymer. Other examples of materials suitable for use in the present invention as elongated members include tapes or yarns disclosed in U.S. Patent Nos. 5,993,711 and 6,045,923 (assigned to Lankhorst Indutech B.V.), incorporated by reference. According to the former, the profile of the elongated member may include one or more longitudinal ribs and/or longitudinal grooves on one or more surfaces. According to the latter, it is possible that an elongated member may include a central layer prepared from a blend of high density polyethylene and one or more other polyolefins, whereby the amount of high density polyethylene is predominant, i.e. more than 50% by weight. More in particular, the central layer is prepared from a blend of 50 to 90 wt. % of high density polyethylene ($>940 \text{ kg/m}^3$) and 10 to 50 wt. % of (linear) low density polyethylene ($<925 \text{ kg/m}^3$), very low density polyethylene ($<910 \text{ kg/m}^3$), or combinations of these products. Additionally an amount of polypropylene may be present to improve the strength of the material.

[0026] The materials of the present invention may offer a range of material properties. Without limitation, by way of example, materials in accordance with the present invention may exhibit a modulus of elasticity of at least about 13 GPa, and more specifically at least about 18 GPa, as measured by ASTM D-638 and a tensile strength of at least about 150 Mpa, and more typically at least about 300 MPa, as measured by the following ASTM test method D-638.

[0027] In instances when the intermediate form is a single layer, as well as in instances when it is desired to have a plurality of layers as part of an intermediate form, one or more layers may be processed for preventing separation of individual structural units, the respective layers, or both. For example, for a single or multi-layer form, one or more of the layers may be secured (and optionally secured to each other for a multi-layer form) in a suitable manner, such as by thermally joining the structural units along at least a portion of one, two or more of the edges of the form. Other approaches to processing

may be employed, such as a mechanical step (e.g., crimping, fastening, stapling, riveting, stitching or otherwise), an adhesive joining step (e.g., with a drop or bead of adhesive, a tape or otherwise), or a combination. In this manner it is possible to readily handle the intermediate forms, such as for transport, storage, placement in a tool cavity or otherwise, while reducing the likelihood that individual structural units will become separated to the extent that the intermediate form integrity is compromised.

[0028] One of the advantages of the present invention is derived from the recognition that, when employed, typical oriented polymeric materials useful for the elongated members of the present invention generally possess a thermal processing window within which it is possible to deform the material but also within which the material retains substantially all of its microstructural orientation, thereby substantially preserving its mechanical characteristics as a result of processing according to steps of the present invention.

[0029] The present invention accordingly affords a convenient and reliable way to operate within the thermal processing window of the material, thus permitting for predictable and reproducible characteristics in the resulting articles.

[0030] As indicated, for fabricating the articles in accordance with the present invention, the intermediate form is provided and handled according to a process by which relatively precise control is exercised over the deformation of the form. Desirably, as the intermediate form is deformed, care is taken particularly to control the wall thickness of the resulting three-dimensional form, the orientation of the elongated members relative to each other within the resulting three-dimensional form, the molecular orientation of the molecule polymer of the elongated member, or any combination thereof.

[0031] It may be possible herein to employ an operation by which the intermediate form, prior to shaping and consolidating, is rigidly secured (e.g., clamped at, near or along any edges. However, a particularly preferred approach involves supporting the intermediate form during shaping so that the form is displaceable (e.g., affords slippage of the form relative to any holding tool) during deformation. By way of illustration, with reference to Figs. 1A-1D, it

is envisioned that an intermediate form 10 will be mounted within a suitable structure 12 (e.g., frame). A shaping tool 14 will deform the intermediate form 10 (e.g., against a die 16) effectively resulting in at least one shaped region 18 and a periphery region 20 generally adjoining (e.g., external of) the shaping region. Typically the structure 12 incorporates one or more biasing members 22. Any biasing members employed typically are selected and located so that they are capable of applying a biasing force in response to a force realized by an intermediate such form while the form is being deformed. In this regard, such biasing mechanism typically will be adapted for providing a biasing force in a direction parallel to the force of any deforming tool (e.g., as in Fig. 1E). It may also be adapted for providing a biasing force in a direction normal during a cycle to the deforming tool force (combinations of the two may also be employed). The biasing members may be connected directly to the intermediate form, to the forming apparatus, to a mounting frame (as described herein) or to some other structure adapted for co-acting with the intermediate form for controlling displacement during deformation of the intermediate form. Biasing may be achieved using any suitable mechanism. Examples include springs, solenoids or other electromagnetic devices, pistons, any combination thereof, or another like work member that is resilient, reciprocates, or both.

[0032] An example of one particular approach to shaping of the intermediate form (whether single layer or multi-layer) involves the employment of a resilient (e.g., spring-biased) structure, such as a spring-loaded frame, that carries the intermediate form 10, whether or not consolidated. For example, a shaping tool is brought together with a die 22, with a frame-mounted form therebetween. The resiliency of the form holding structure helps to avoid thinning of the form that would normally occur upon forming without the frame, and thus helps to result in a shaped intermediate form that includes a substantially constant wall thickness and smooth, ruck-free exposed surface throughout substantially the entirety of the usable portion of the resulting form.

[0033] It should be appreciated that various configurations of tooling may be employed for affording the desired combination of holding and displacement

necessary for successful deformation. For example, one particular approach is shown schematically in FIG. 1E, where the frame is itself resiliently mounted, (e.g., by a spring), so that the intermediate form is shaped while allowing flow of the structural units to maintain wall thickness during application of pressure. The resilient mounting can be such that the frame is suspended by one or more springs (e.g., the weight of the frame and any other optional force displaceably clamps the intermediate form), the frame is mounted so that it is biased toward the intermediate form during deformation, or a combination thereof.

[0034] It should be appreciated that for multi-layer forms where each layer is able to move over and relative to each other (e.g. sliding independent of each other), the present apparatus may be adapted for maintaining the amount of the movement consistent throughout the form under all loads.

[0035] The general approach of the present invention is described in further detail with reference to FIGS. 2-5. Pursuant to such approach, as with Figs. 1A-1E, conditions are selected for processing the intermediate form during deformation so that controlled deformation within the shaped region is achieved, and more specifically, relatively uniform wall thickness is obtained where desired, orientation of the elongated members relative to each other is generally preserved, extreme deviations of morphology, crystallinity or both (and resulting properties) of oriented polymers used in the intermediate form is substantially avoided, a smooth, ruck free exposed surface results over generally the entirety of the shaped region, a depth of draw ratio (the relationship of depth to width of a part) of about 0.1:10 to about 5:1 (e.g., about 1:1) is realized, layers of a multi-layer intermediate form are allowed to move relative to each other, damage of the elongated members due to excessive elongation is substantially avoided, or any combination thereof (preferably a combination of all of the above). For example, one particular approach is to control the forces that hold the intermediate form during deformation. That is, described generally relative to Figs. 1A-1E, the force is selected and varied as necessary such that the periphery region of the intermediate form undergoes at least some displacement in response to the forces exhibited during shaping. For sake of illustration,

reference to Figs. 3A and 3B show displacement in the form of lateral slippage, that can be seen by the lateral movement of a Point A on the intermediate form relative to a fixed reference point X.

[0036] One specific example of a system for permitting displacement of the peripheral region in accordance with the present invention is illustrated with reference to the tooling of FIGS. 2-4, particularly as employed (without limitation) in the apparatus described generally in FIG. 5. As seen, for aid in handling of the intermediate form, the intermediate form may be positioned in a suitable carrier frame 26. By way of example, without limitation, FIG. 2 illustrates a carrier, that includes at least one carrier member, and more specifically a plurality of separable co-acting carrier members, such as a first carrier member 28 and a second carrier member 30. Though other structures are possible by which the first carrier member and the second carrier member are configured for receiving the intermediate form (e.g., they may be of similar dimensions for opposing each other about their peripheries), one attractive approach involves employment of carrier members each of different dimensions, such as for permitting nesting one of carrier members in the other, with the intermediate form located between them. With particular reference to FIGS. 3A and 3B, one such approach is to form a receiving structure (e.g., a well, a groove, ledge or the like) in one of the carrier members, into which a protuberance (e.g., a pin, a flange, a wall or the like) of the other member can penetrate. In general, however, the structure of the co-acting carrier members will be such that when the intermediate form is placed in the carrier, the intermediate form will not be fixed in place but will be displaceable (e.g., by lateral slippage) in response to a deformation force.

[0037] Typically, where the carrier is adapted to carry the intermediate form generally about at least a portion of entire periphery region 20, the carrier frame 26 will be adapted to have an opening through the deformation tool can pass during processing. The intermediate form may be carried by the carrier so that the form is in contact with the carrier over some or all of the carrier. Though the embodiment of FIGS. 2A and 2B show an enclosed structure, it is also possible that the carrier frame is divided into a plurality of laterally separate components.

The separable co-acting carrier members optionally may be physically connected to each other, such as by one or more pivotal members (e.g., a hinge), fastener, magnets, a combination thereof or the like.

[0038] Turning to the drawings of FIGS. 3A and 3B, taken with reference also to FIG. 5 (showing one example of a press 32), there is shown an approach by which the intermediate form can be displaced during deforming. As illustrated generally, deforming will be achieved by the use of the shaping tool (e.g., a punch 34), which will act against an opposing shaping tool (e.g., die 36). A blank holder 38, having an exposed wall surface 40 is disposed adjacent to the deformation tooling (e.g., outside the perimeter of the punch 34, the die 36, or both), and can be mounted for independent movement relative to the punch 34, the die 36, or both. In the embodiment shown, the punch 34, the die 36, or both are removably separable from respective platens or other support structure 44 and 46 (e.g., it can be removably held in place by a vacuum, by fasteners, or the like). It is also possible that the tool and platen are integrated into a single structure. Further, it is possible that the wall surface may be dimensioned or otherwise configured so that it bears against one or more of the carrier members 28 or 30.

[0039] As indicated, mounted for translation independently of the shaping tools, and for displaceably holding the intermediate form during deformation will be the blank holder 38. Preferably, the blank holder 38 is configured so it does not rigidly fix the intermediate form during deformation. In this regard, the blank holder 38 may include one or more protuberances 42 (e.g., an annular protuberance) that is adapted for contacting and displaceably holding the intermediate form during deformation. Such contact with the intermediate form may be in combination with the holding of the carrier frame 26, or independent of any carrier frame contribution. In another embodiment (not shown), the blank holder is configured so that instead of or in addition to directly contacting the intermediate form, it bears against the carrier frame.

[0040] The blank holder 38 may be independently mounted in any suitable manner. It has been found, however, that an approach by which the blank holder

38 is carried in accordance with the above teachings helps to realize the desired flow of the intermediate form within the apparatus during deformation. That is, the blank holder (alone or in combination with the carrier frame) effectively constitutes a resilient frame assembly that allows flow of the individual structural units of the intermediate form to maintain wall thickness during application of pressure. The resilient mounting can be achieved in a number of ways. For example, as described, the blank holder may be suspended by one or more springs (e.g., the weight of the blank holder and any other optional force displaceably clamps the intermediate form), the blank holder may be mounted so that it is biased toward the intermediate form during deformation, or a combination thereof.

[0041] One particular preferred approach, as shown in FIGS. 3A and 3B, and FIG. 5 shows an approach by which the blank holder 38 is vertically suspended by one or more shafts 48 along which the blank holder 38 may be fixed or freely moveable. One or more biasing members (e.g., springs) 50 are located for biasing the blank holder 38 toward the intermediate form (not shown in FIG. 5). The biasing members are selected so that they exert a force toward the intermediate form sufficient to displaceably engage the intermediate form (and optionally any carrier frame) sufficient to permit the desired amount of flow of the intermediate form across the engaging surfaces of the blank, the carrier frame or both, during deformation, while at the same time resisting the deformation forces so that the intermediate form remains sufficiently secured so that deformation of the intermediate form can occur.

[0042] Selection of the biasing force thus can be accomplished by consideration of the desired characteristics of the resulting shaped intermediate form. Thus it is possible that the resulting shaped form, over a range of depth of draw ratios, will realize a predetermined wall thickness throughout the shaped form, orientation of the elongated members relative to each other will be generally preserved, extreme deviations of morphology, crystallinity or both (and resulting properties) of any oriented polymers used in the intermediate form will be substantially avoided, a smooth, ruck free exposed surface results over

generally the entirety of the shaped region will occur, a depth of draw ratio (the relationship of depth to width of a part) of about 0.1:10 to about 5:1 (e.g., about 1:1) can be realized, layers of a multi-layer intermediate form are allowed to move relative to each other, and damage of the elongated members due to excessive elongation is substantially avoided.

[0043] Other factors may be taken into account in the selection of the biasing force. Alternatively, a biasing force may be selected and one or more processing parameters may be varied in response to the selected biasing force. For example, without limitation, it is also possible to vary the rate of deformation tool travel, vary the load within a cycle, vary the temperature during the cycle, vary the number of load cycles or any combination thereof.

[0044] Typically, the shaping that will occur during steps represented by FIGS. 3A and 3B will be performed at an elevated temperature, e.g., a temperature above room temperature that affords softening of the material of the intermediate form, and potentially at a temperature above the melting point of the material on the outer surface of elongated members in the intermediate form. Thus, the temperature of components of the shaping tooling, the platens, any other associated components of the apparatus, or any combination thereof, may be controlled as desired. The temperature of two or more components may be independently maintained. For example, the platen 44 may be heated or chilled for heating or cooling a shaping tool (e.g. punch 34). A third platen 52 may be included for heating or cooling the shaping tool (e.g., punch 34) when it is in a retracted position. The opposing shaping tool (die 36) also may be heated or cooled. For example, the second platen 46 may be adapted for cooling or heating the shaping tool (e.g., die 36) positioned in it. As desired, insulation 54 may be employed between components of the apparatus for maintaining discrete thermal zones. It should be appreciated that during any deforming step the temperature of the intermediate form may be kept substantially constant for one or more predetermined periods of time (e.g., for at least about 5 seconds to about one hour, and more preferably about 30 seconds to about 5 minutes; longer or shorter times being possible also). It may also be varied over a range of

temperatures for achieving the desired characteristics. Further the intermediate form may be pre-heated to a predetermined first temperature and maintained at that temperature during deforming, or heated or cooled to a different temperature during deforming.

[0045] In accordance with the above, with reference to FIGS. 3A and 3B, it is therefore seen that deformation of an intermediate form can be accomplished by loading the intermediate form 10 into the carrier frame 26, which is then located so the intermediate form is between opposing portions 34 and 36 of the shaping tool. Load is applied to the intermediate form by advancing the shaping tool portions toward each other. The blank holder 38 (e.g., using protuberance 42) will engage the intermediate form, along with any engagement contributed by the carrier frame 26. It can be seen that the blank holder 38 can be adapted (e.g., through its dimensions, operation parameters, or otherwise) so that the blank holder engages the intermediate form at any desired time. For example, the blank holder 38 may initially engage the intermediate form for resisting a deformation load before, simultaneously with or after when the application of the deformation load is commenced.

[0046] It can be seen that upon deformation load being applied, and at least after commencement of deformation, the periphery region of the intermediate form will be held by the blank holder 38. The biasing force, however, will permit the periphery region to translate laterally. This is illustrated by showing the relative translation of reference point A relative to reference point B in FIGS. 3A and 3B.

[0047] The controlled displacement of the intermediate form during deforming helps to manage the amount of the intermediate form material that enters the shaped region, helping to avoid excess material that would be prone to folding or creasing. Further, during this step of deformation, particularly under conditions of elevated temperature and pressure from the shaping tool, it is like that consolidation of the intermediate form will occur. Thus, it can also be seen that, if desired, a separate step of consolidating the intermediate form before shaping can be obviated. Consolidation may be performed in any suitable manner and

may be performed in a single stage operation or as part of a plural stage operation. In the course of consolidation, an intermediate form that typically is initially drapable upon itself (e.g., the form itself is pliable, adjoining structural units are movable relative to each other, or both) is consolidated, the form will become at least semi-rigid, preferably so that it is capable of supporting its own weight. It will be typical that upon shaping and consolidation, the forms of the present invention will be capable of long term shape retention, e.g., at ambient, greater than 2 weeks, more specifically greater than one month, and even more specifically greater than 3 months. In this manner, it is contemplated that a form manufacturer can generate an inventory of forms, which can then be stored for an extended period until needed for assembly into a composite. Consolidated forms, particularly those that include a polyolefin as its major constituent, typically will exhibit a consolidated density ranging from about 0.75 to about 0.9 g/cm³, and more specifically about 0.83 g/cm³. It is also preferred that the consolidated forms exhibit a density of at least about 80% of theoretical density, more preferably a density of at least about 90% of theoretical density (e.g. higher than 95% of theoretical density, such as at least 99% of theoretical density).

[0048] The consolidating processing step effectively will irreversibly join adjoining structural units together, and thus consolidating may be done by a step of gluing, melting, fastening or otherwise assembling the units. One particular approach made convenient by the present invention is to heat the intermediate form to a temperature above the melting point of at least one of the materials in the form to cause the material to melt and fuse, and effectively weld with adjoining units.

[0049] The heating step may be performed using any of a number of approaches. For example, it is possible that the form is pre-heating remotely before deformation and delivered to the deforming apparatus at an elevated temperature, whereupon deformation pressure is applied. In addition, or as an alternative to the preheating step, heating may occur at or within the deforming apparatus. For example, a die, a punch, a combination thereof or another tool for deforming the form can be preheated. In one approach, if off-line pre-heating

is employed, the temperature within the intermediate form may be raised to its requisite processing temperature within the tool.

[0050] Any heating step in accordance with the present invention may be performed by conduction, convection, radiation or any combination thereof. An oven may be used as a heat source. A radiofrequency heat source, a microwave heat source or both may also be used. Heating may be done in an inert atmosphere, in air, or in another suitable atmosphere. Further, heating steps may include a plurality of steps each performed at a different temperature, each performed under application of a different pressure, or a combination thereof.

[0051] By way of example, without limitation, for a polyolefin based intermediate form, a preheat step (if employed), may be performed by heating the intermediate form in the absence of an applied deformation load to a temperature of at least about 60 °C, and preferably below about 120°C (e.g., about 100°C). This may be maintained for several minutes, or possibly even a day or longer (e.g., about 0.5 to about 20 hours). Thereafter, a deformation load may be applied, preferably while the intermediate form is subjected to heat (such as from about 120 to 160°C (e.g., about 140°C) or higher), such as that for realizing a deformation pressure of about 10 to about 200 Bar (e.g., about 20 to about 140 Bar, and more specifically at least about 80 Bar). The elevated temperature and pressure is maintained for about 1 to about 10 minutes, and more specifically about 3 to about 5 minutes (e.g., about 4 minutes) so that consolidation and deformation may occur. It should be realized that longer or shorter times, and/or higher or lower pressures may be employed depending upon the size of the intermediate form, with the above ranges being generally applicable for an intermediate form that is consolidated to a thickness of about 1 to about 10 mm (e.g., about 2 to about 7 mm).

[0052] Turning to FIGS. 4A and 4B, there is illustrated an example of an optional secondary shaping operation. In particular, the shaping of articles in accordance with the present invention envisions the possibility of employing a secondary stamping operation, and more particularly a shear edge deformation step. The secondary step may be performed under one or more elevated

temperatures, but more typically will be conducted at or below room temperature (e.g., from about 0 to about 20°C, and more specifically up to about 15°C). Prior to the time of the secondary shaping operation, typically the intermediate form will be at least partially consolidated (e.g., through the heat involved in the operations illustrated in FIGS. 3A and 3B). However, it is possible that consolidation will occur during the secondary shaping operation, particularly since sustained pressures for about 0.5 to about 5 minutes (e.g., about 1.5 to 3 minutes) during the secondary shaping operation may be on the order of about 50 to about 250 Bar, and more specifically about 100 to about 200 Bar (e.g., about 175 Bar). Accordingly, in view of the above, it is possible that the use of the carrier frame 26, the blank holder 38, or both, may be omitted. As with the other examples herein, it will be appreciated upon review of these teachings that the above is not intended to cover every scenario in which the present inventions may be employed. Variation of the parameters may be made depending upon the results sought, the size of the blank that is processed, the nature of the material that is processed, and other related considerations. For example, longer or shorter times may be employed, as may be higher or lower pressures than those recited in the above discussion.

[0053] One possible benefit of the secondary shaping operation will be that additional strain hardening (it being recognized that before or during consolidation at elevated temperatures, strain elongation of about 10 to about 40% may be employed) can occur in the intermediate form during the shaping step, and will therefore impart improved mechanical properties to the shaped articles. By way of example, strain elongation be kept below about 15% and more preferably below 10%. Accordingly, it is possible that the secondary shaping operation may occur using differently dimensioned shaping tooling (which optionally may be configured to be cooled during shaping) than in the primary operation. It may also employ the same tooling as in the primary operation, but as a result of shrinkage or relaxation of the intermediate form after the primary operation, a gap results at the tooling/intermediate form interface, affording volume to enable additional deformation. In yet another approach, there

may be no gap, and the material of the intermediate form is thus further compressed between the tooling for achieving further consolidation, or local densification within a desired region. In another approach, the secondary operation is employed for preserving the dimensions and geometry of the shaped intermediate form during cooling. Any combination of the steps recited in this paragraph may also be employed.

[0054] Thus, pursuant to FIGS. 4A and 4B, one or more tools 60, such as a tool that incorporates at least one shear edge 62 may be substituted for at least one of the shaping tools of FIGS. 3A and 3B. Optionally, alternative tooling 36' carried in platen 46' may be substituted as well. It can be seen that the ability to deform the intermediate form without heating it for softening thermoplastic constituent materials is an advantage made possible by the present invention.

[0055] It can be seen that another of the benefits that may be possible using the present invention is the ability to stamp the shaped articles (whether symmetrical or asymmetrical in geometry) that require minimal or no additional finishing steps. This also offers a benefit of reducing subsequent cutting operations. The stamping step may also employ suitable pressure so that consolidation of the intermediate form occurs during the stamping. It should be recognized that stamping need not only be cold stamping. Stamping a heated form at an elevated temperature is also possible.

[0056] It is possible that when a plurality of stages are employed for shaping the forms of the present invention a plurality of separate presses may be employed. It is also possible to configure tooling for a single press that accomplishes the combination of functions performed in the separate stages.

[0057] The elegance in the simplicity of this approach is still further manifested by the ability to use a single apparatus for deforming a wide range of intermediate forms of different size, geometric, complexity, material characteristics, and the like, simply by the selection of an appropriate interchangeable biasing member (e.g., a spring). To this point, it has been recognized herein that selection of the appropriate biasing member may be achieved by determining a threshold stress, (e.g., a stress beyond which the

elongated members of the intermediate form will plastically deform unpredictably) and selecting the biasing member so that it exerts only enough force upon the intermediate form (e.g., in the periphery region) that lateral displacement of the intermediate form will occur before the threshold stress is realized.

[0058] The manner of supporting the intermediate form so that it is displaceable during shaping can be achieved by any of a number of alternative approaches as well. By way of example, one approach is to employ about the periphery of the region for shaping with one or more physical displacement resistors. For instance, the intermediate form may include variations in topography, a surface protuberance, or the like which can offer a resistive force when coming into contact with an opposing member associated with the tooling. The resistor may be structured so that it progressively pulls through the tooling upon a threshold force.

[0059] Another approach may be to apply at least a partially continuously variable clamping force (e.g., by a mechanical, electromechanical, or electromagnetic clamping mechanism), to the intermediate form while deforming the intermediate form. The clamping force can be cycled, for example so that, while deformation occurs, the clamping force is briefly reduced and during the brief reduction the intermediate form can be displaced, wherein upon reinstatement of the clamping force the intermediate form is restored to fix the periphery region. The intermittent steps of applying a fixed clamping force and force reduction can be repeated as desired in regular or irregular periods.

[0060] Without intending to be limited thereby, one specific example of the present invention involves an apparatus such as in FIG. 5. Again, as with the other examples herein, it will be appreciated upon review of these teachings that the example is not intended to cover all scenarios in which the present inventions may be employed. Variation of the parameters may be made depending upon the results sought, the size of the blank that is processed, the nature of the material that is processed, and other related considerations. Six carbon steel springs are located about the apparatus for biasing the blank holder toward an intermediate form when disposed between a first and second shaping tool. Each spring is

rated at 32.16 (N/mm) per cm – (that is, rate per mm per cm). Given an original length, for each spring, L_0 of 130 mm, a compression spring constant is realized of $32.16 \text{ [N/(mm/cm)]} / 13 \text{ [cm]} = 2.47 \text{ [N/mm]}$. Given each spring compresses by 76 mm, a force contributed by each spring is obtained of $76 \text{ mm} \times 2.47 \text{ [N/mm]} = 188 \text{ [N]}$.

[0061] This force is realized when, for instance, the intermediate form is shaped while at an elevated temperature. The total force (F) distributed over the form, which if contributed by the blank holder springs $F = 188 \times 6 \text{ [N]} = 1128 \text{ N}$.

[0062] Using this force, the apparatus can readily press out a deep draw depth of draw ratio (the relationship of depth to width of a part) of about 0.1:10 to about 5:1 (e.g., about 1:1) on a relatively large blank (e.g., about 350 to about 550 cm^2 in area) from a multilayer intermediate form made of from about 14 to 34 layers of woven polypropylene sheet. It also acts to prevent reversion, not just prevent slip.

[0063] In this example, carrier frame dimensions are about 22.5 cm per side, with the perimeter wall defining the internal opening being about 13 mm wide. This presents an area of about 0.011 m^2 . If the carrier were to take all this pressure alone, this equates to a pressure of 102 kPa or 1 Bar. If it is assumed that the force also acts on all of the area contacted by the blank holder, then the force acts over an area of 0.051 m^2 and the pressure is actually 22.3 kPa or 0.22 Bar.

[0064] It should be appreciated that in one particular aspect of the present invention, many of the foregoing properties are the result of a combination of materials selection and processing conditions that result in the preservation of substantial morphology (and specifically orientation) within the elongated member component of the intermediate form throughout all processing steps until completion of the finished article. Specifically, one approach of the present invention is to avoid any step of consolidating the intermediate form prior to thermoforming, stamping or other intermediate form shaping step. Prior materials would employ a consolidation step prior to any such intermediate form shaping step. However, such orientation of preservation is not mandatory for many of the

novel embodiments disclosed herein. Accordingly, the skilled artisan will recognize that various of the prior art materials that employ a consolidation step prior to an intermediate form shaping step may still be employed for making composites within such embodiments. In addition, it is possible that multi-layer intermediate forms may be employed with fewer than all of the layers having been processed for maintaining orientation.

[0065] Reference herein to “first” and “second” are not intended as limiting to combinations that consist of only first and second items. Where so-referenced, it is possible that the subject matter of the present invention may suitably incorporate third, fourth or more items. Reference to “elongated member” is not intended to foreclose coverage of a plurality of elongated members. Except where stated, the use of processing steps such as “consolidating” or “shaping” or their conjugates do not require complete consolidation or shaping; a partial consolidation or shaping is also contemplated. Moreover, the disclosure of “a” or “one” element or step is not intended to foreclose additional elements or steps.

[0066] Unless stated otherwise, dimensions and geometries of the various embodiments depicted herein are not intended to be restrictive of the invention, and other dimensions or geometries are possible. Plural structural components step can be provided by a single integrated structure or step. Alternatively, a single integrated structure step might be divided into separate plural components or steps. However, it is also possible that the functions are integrated into a single component or step.

[0067] In addition, while a feature of the present invention may have been described in the context of only one of the illustrated embodiments, such feature may be combined with one or more other features of other embodiments, for any given application. It will also be appreciated from the above that the fabrication of the unique structures herein and the operation thereof also constitute processes in accordance with the present invention.

[0068] It is understood that the above description is intended to be illustrative and not restrictive. Many embodiments as well as many applications besides the examples provided will be apparent to those of skill in the art upon reading the

above description. The scope of the invention should, therefore, be determined not with reference to the above description, but should instead be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. The disclosures of all articles and references, including patent applications and publications, are incorporated by reference for all purposes. The omission in the following claims of any aspect of subject matter that is disclosed herein is not a disclaimer of such subject matter, nor should it be regarded that the inventors did not consider such subject matter to be part of the disclosed inventive subject matter.

CLAIMS

What is claimed is:

1. A process for forming a shaped three dimensional article, comprising the steps of:

deforming an intermediate form that consists essentially of a plurality of thermoplastic elongated members while clamping the intermediate form during the deforming in such a way that while a force is applied for deforming the intermediate form, the intermediate form is free to move within a predetermined limit; and

optionally, at least partially consolidating the thermoplastic elongated members of the intermediate form for forming a three dimensional article.

2. A process according to claim 1, wherein the thermoplastic elongated members are tapes that include polypropylene.

3. A process according to claims 1 or 2, wherein the at least partially consolidating step occurs during the deforming step.

4. A process according to claims 1 through 3, wherein the displaceable clamping is performed by a spring biased blank holder.

5. A process according to claims 1 through 4, further comprising a step of preloading the intermediate form in a carrier frame and maintaining the intermediate form in the carrier frame during at least the deforming step.

6. The process according to any of claims 1 through 5, further comprising heating the intermediate form to a temperature such that a central portion of the elongated members of the intermediate form remains below their melting point but soften sufficient for facilitating deforming and avoiding rupture of the elongated members during the deforming.

7. The process according to claim 6, wherein the elongated members have an oriented molecular portion.
8. The process according to claim 7, wherein the temperature of the heating is maintained so that orientation of the oriented portion of the elongated members is substantially preserved throughout the deforming step.
9. The process according to any of claims 1 through 8, further comprising a step of shear edge stamping the form.
10. The process according to claim 9, wherein the deforming step and the shear edge stamping step is performed using a common press.
11. The process according to claim 10, further comprising employing for the deforming step and the shear edge stamping step at least two independently moveable tools.
12. The process according to claim 11, further comprising locating the at least two independently moveable tools on the same side of the intermediate form prior to the deforming and stamping steps.
13. The process according to claim 11, further comprising locating the at least two independently moveable tools on opposing sides of the intermediate form prior to the deforming and stamping steps.
14. The process according to claim 9, wherein the deforming step and the shear edge stamping steps are performed in separate presses.

15. The process according to any of claims 1 through 14, further comprising varying the thickness of the intermediate form for forming a resulting three dimensional article having a variable thickness.

16. The process according to any of the claims 1 through 16, wherein the intermediate form includes a plurality of layers.

17. A process for forming a shaped three dimensional article, comprising the steps of:

deforming an intermediate form while clamping the intermediate form during the deforming in such a way that while a force is applied for deforming the intermediate form, the intermediate form is free to move within a predetermined limit; and

at least partially consolidating the intermediate form; and
optionally stamping the intermediate form in a secondary forming operation.

18. The process according to claim 17, wherein the stamping includes a shear edge stamping step.

19. An apparatus for forming a three-dimensional article, comprising:

- a) a first tool for deforming an intermediate form at an elevated temperature;
- b) an optional second tool for stamping the intermediate form; and
- c) a holder for clamping the intermediate form during deforming in such a way that while a force is applied for deforming the intermediate form, the intermediate form is free to move within a predetermined limit.

20. The apparatus of claim 19, wherein the holder includes a plurality of biasing members that bias the holder in a direction parallel to the direction of travel of the first tool in the apparatus.
21. An article made according to any of the processes of claims 1 through 18.

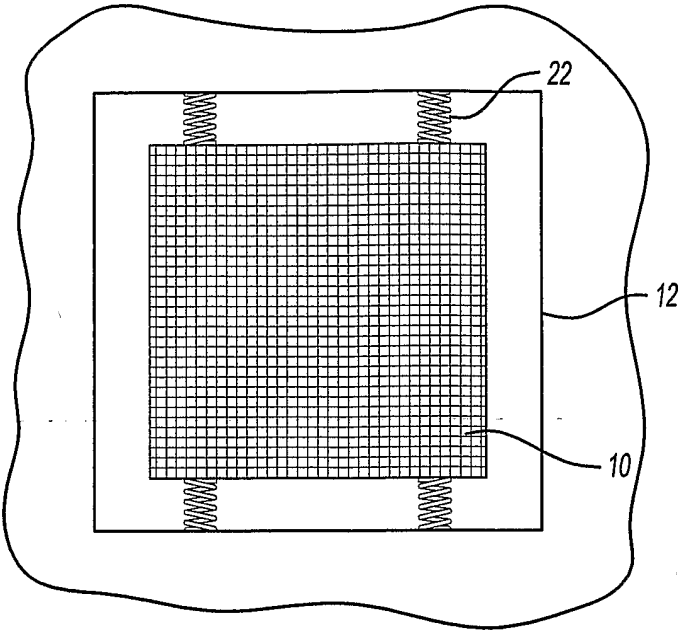


Fig-1A

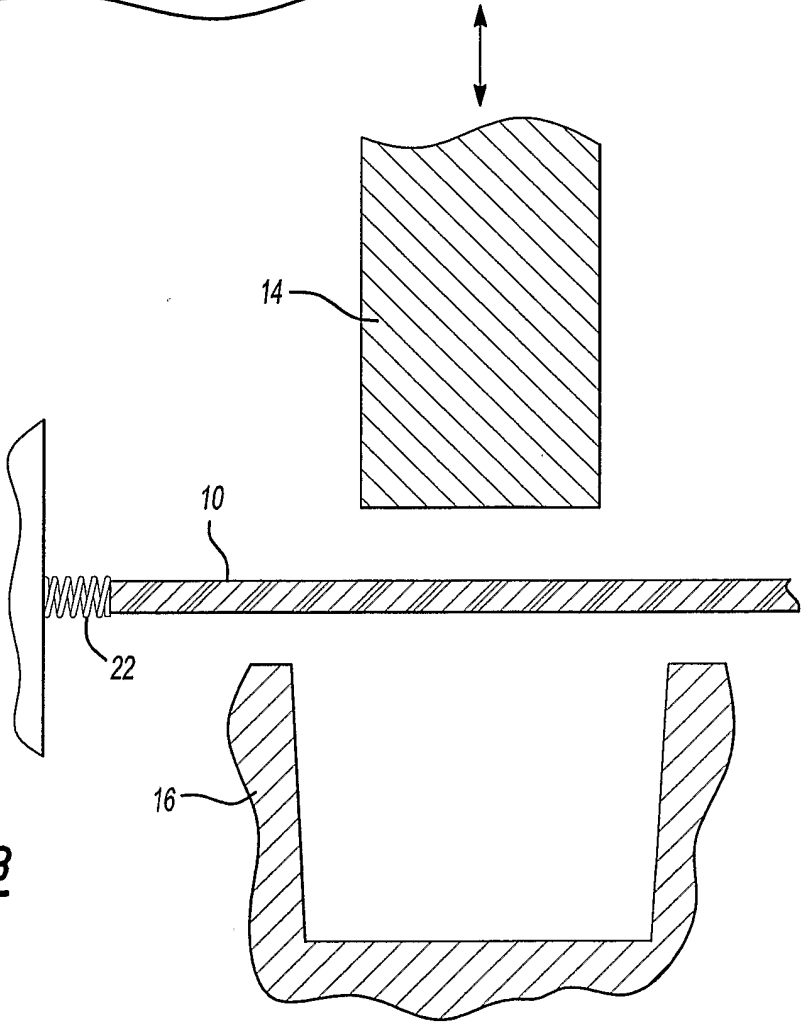


Fig-1B

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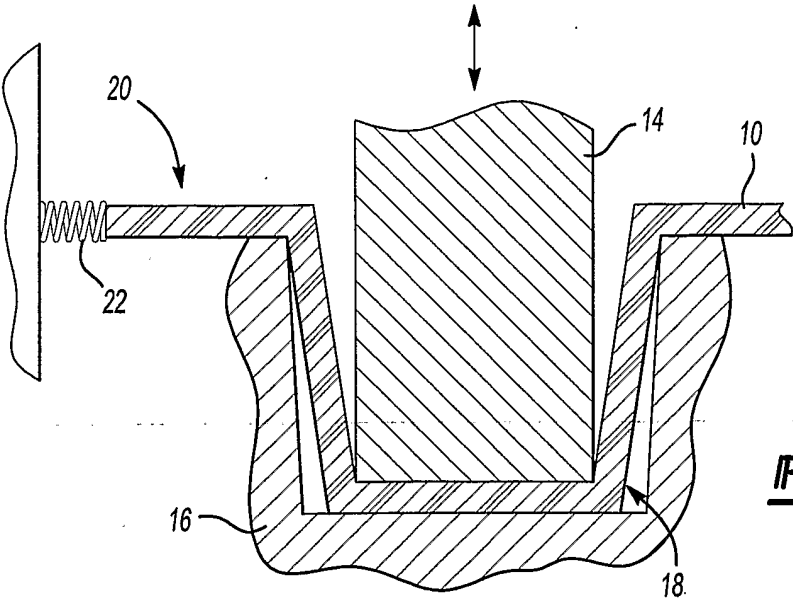


Fig-1C

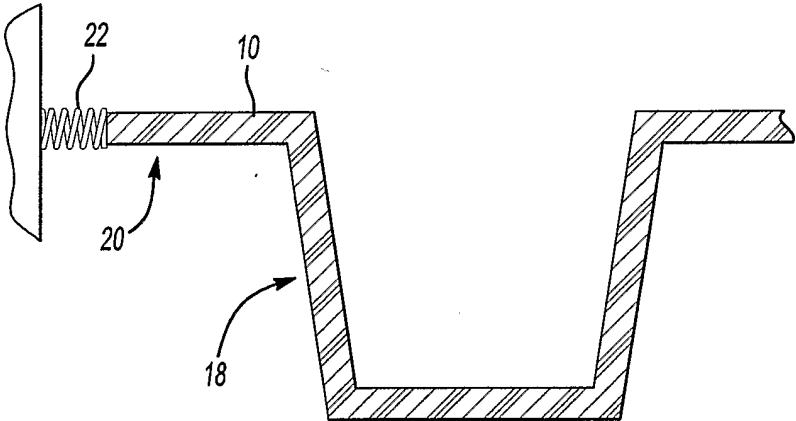


Fig-1D

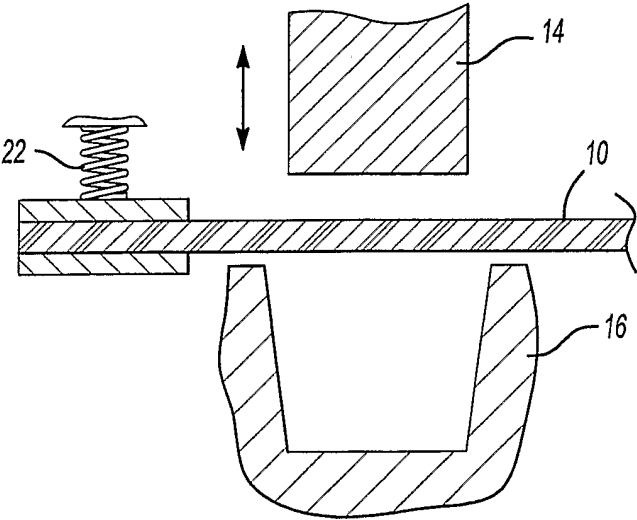


Fig-1E

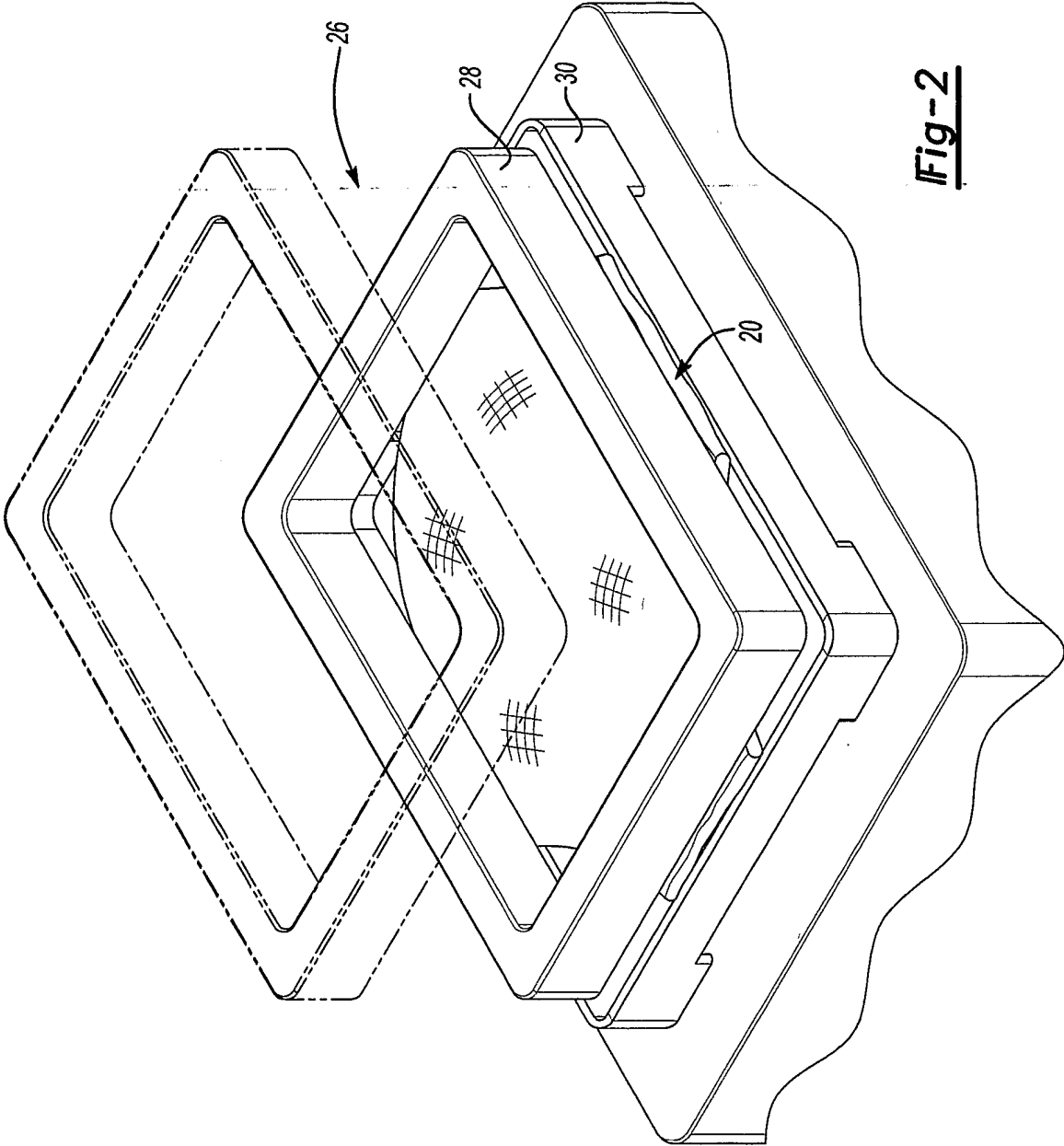


Fig-2

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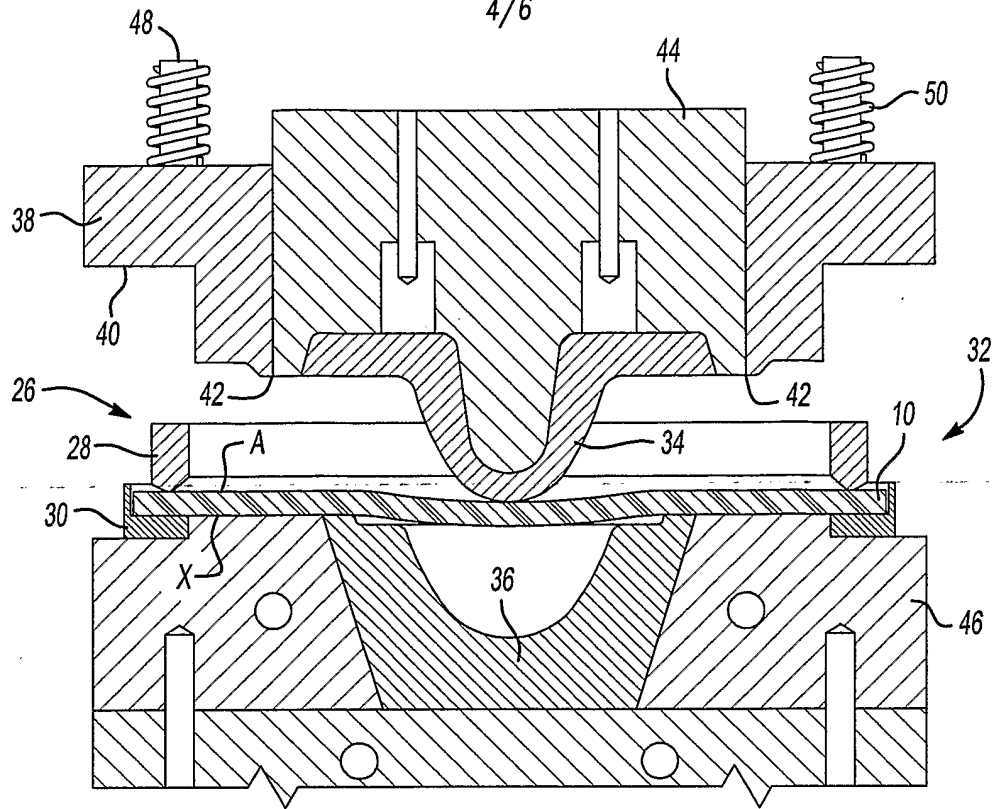


Fig-3A

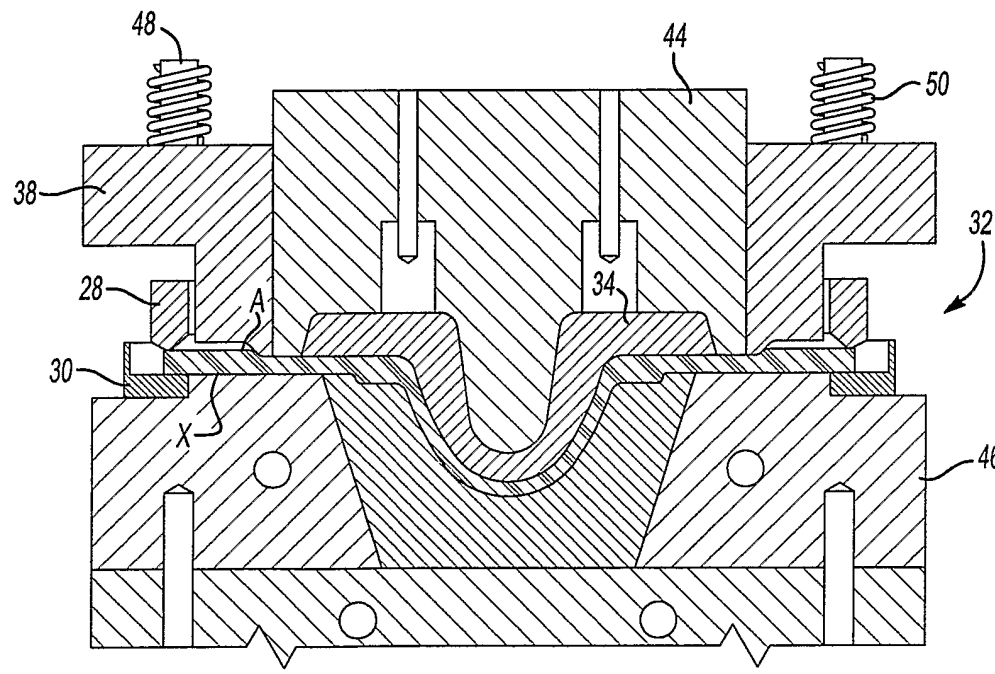


Fig-3B

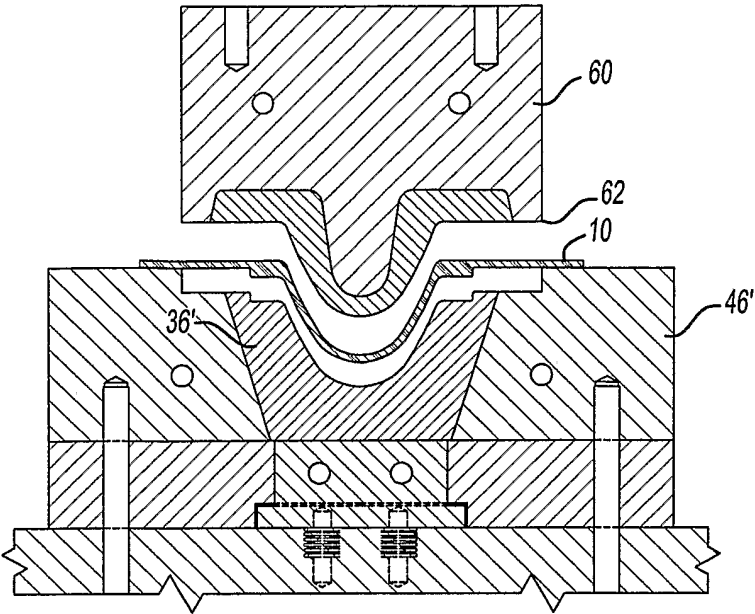


Fig-4A

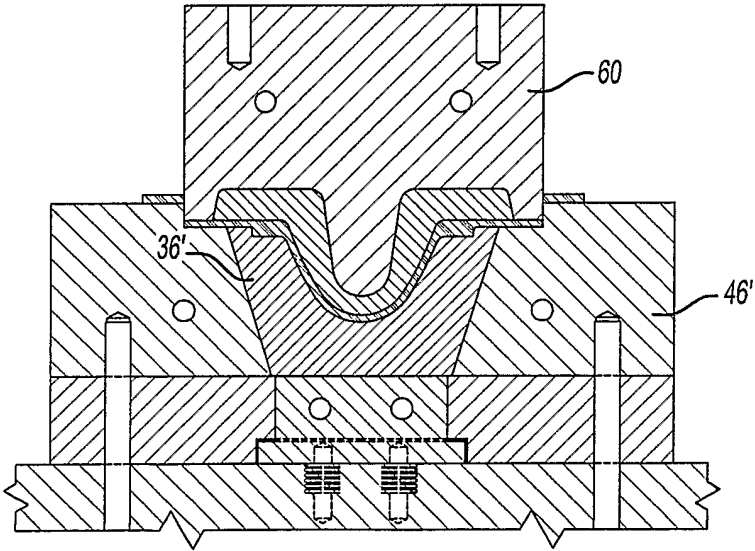


Fig-4B

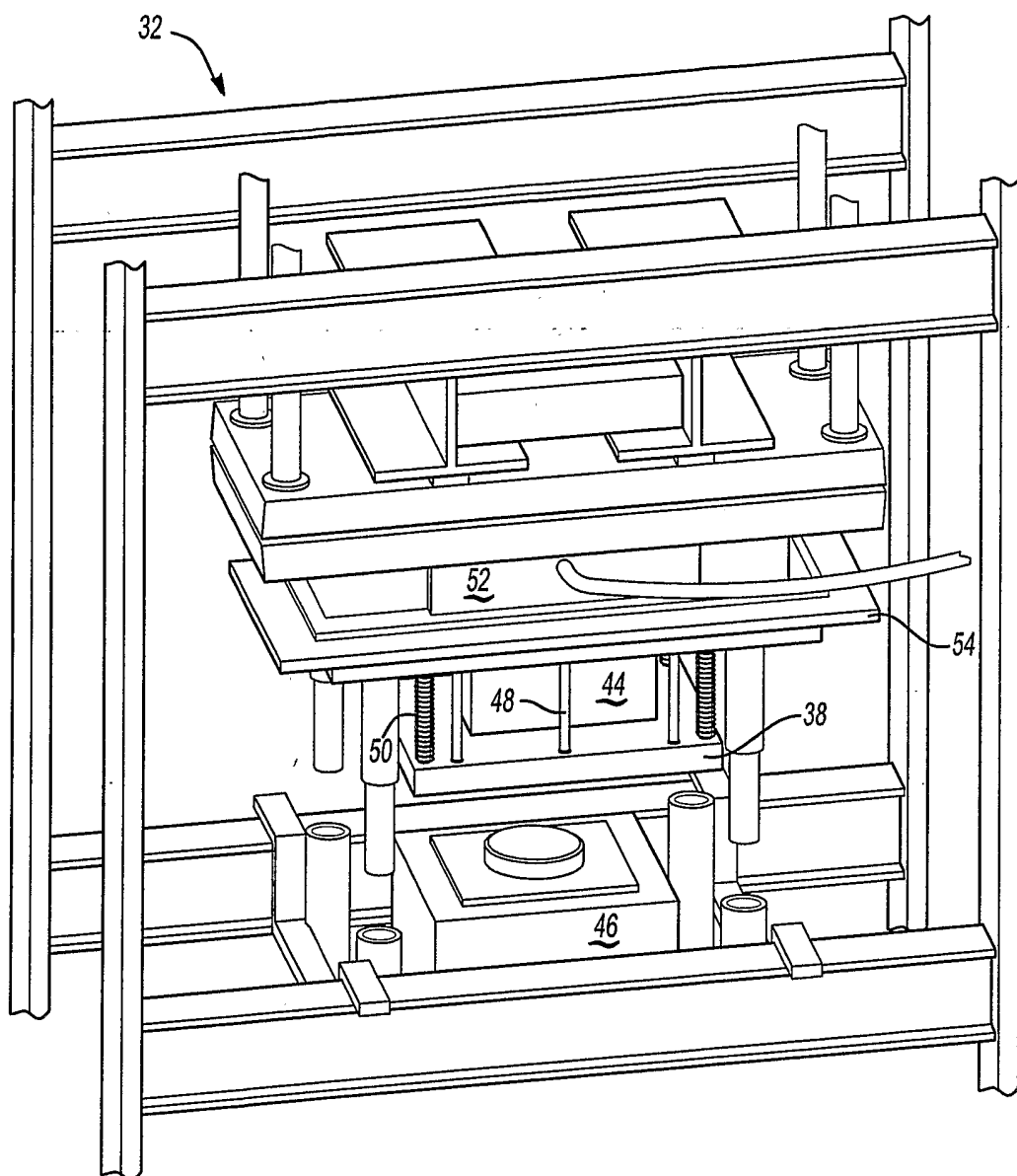


Fig-5

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2005/038091

A. CLASSIFICATION OF SUBJECT MATTER
 B29C51/26 D06M23/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 B29C D06M D01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
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Y	claims 1-4; figure 1	2
X	FR 2 600 936 A (COFIM) 8 January 1988 (1988-01-08) page 2, paragraph 1; claims 1,6; figures 1-8	1,17,19
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X	US 5 200 133 A (DIEUL ET AL) 6 April 1993 (1993-04-06) column 3, line 34 - line 40	1,9
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

A document defining the general state of the art which is not considered to be of particular relevance

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O document referring to an oral disclosure, use, exhibition or other means

P document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

& document member of the same patent family

Date of the actual completion of the international search

6 April 2006

Date of mailing of the international search report

12/04/2006

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2005/038091

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	claim 1; figures 3-6 -----	1,4,17
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A	claim 9; figures 3,5 -----	9
X	US 5 565 053 A (HAPPICH ET AL) 15 October 1996 (1996-10-15)	19
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A	claim 1; figures 1-8 -----	1,4,17
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A	GB 471 618 A (BRITISH CELANESE LIMITED) 8 September 1937 (1937-09-08) claim 1 -----	1,17
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A	US 4 046 611 A (SANSON ET AL) 6 September 1977 (1977-09-06) figure 9 -----	19

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2005/038091

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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