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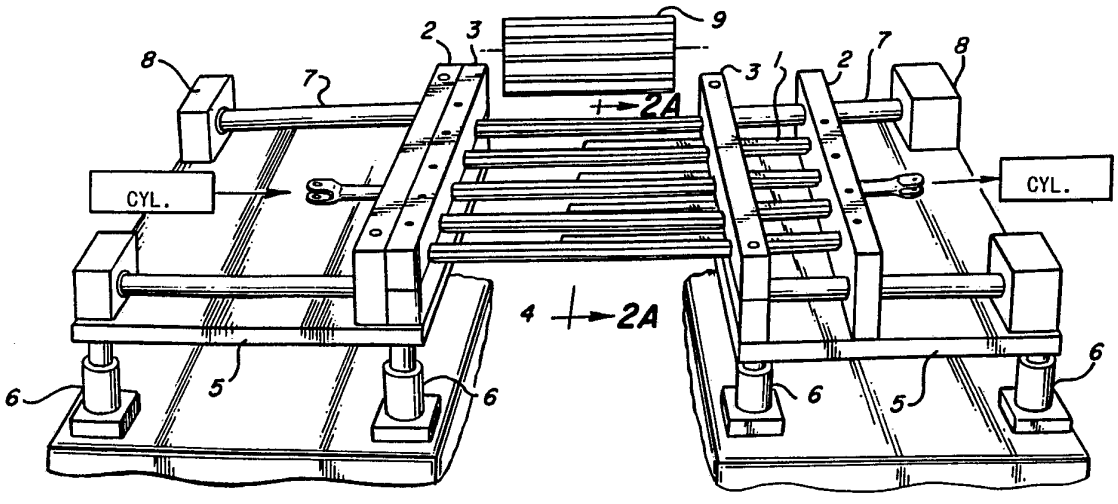
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(54) Title: PROCESS FOR THE PREPARATION OF THERMOPLASTIC HONEYCOMB SHAPED STRUCTURES WITHOUT MACHINING



(57) Abstract

Fiber-reinforced and non-reinforced thermoplastic honeycomb is prepared in a continuous manner one half cell at a time with the aid of formers (1, 4) by laying down a corrugated web of thermoplastic, selectively fusing the node-antinode demes by means of a toothed roller (9), retracting the lowermost set of formers (1) through the use of linear bearings (7) attached to pillar blocks (8), raising the lowermost formers by means of pistons (6) an amount at least equal to the thickness of the fused node-antinode surface, and repeating the process until a honeycomb of the desired depth is prepared. Shaped honeycomb parts are prepared wherein the webs of fiber-reinforced or non-reinforced thermoplastic are slit in a predetermined manner prior to laying on the formers such that the finished honeycomb may be separated by hand into parts having a predetermined geometry.

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PROCESS FOR THE PREPARATION OF THERMOPLASTIC HONEYCOMB SHAPED STRUCTURES WITHOUT MACHINING

Background of the Invention

1. Field of the Invention

The present invention pertains to fiber-reinforced and non-reinforced thermoplastic honeycomb structural materials. More particularly, the subject invention pertains to a continuous process for the preparation of thermoplastic honeycomb having complex three dimensional shapes without resort to current complex and time-consuming machining operations.

2. Description of the Related Art:

The use of honeycomb materials in the aerospace and transportation industries is increasing. While metal honeycomb is satisfactory for many purposes, the need for weight reduction coupled with strength and high modulus has led to the use of honeycomb formed from fiber-reinforcement in a polymer matrix. The polymer matrix may be of a thermosetting or thermoplastic matrix. Honeycombs of engineering thermoplastics not containing fibrous reinforcement have also been used.

A particular advantage of polymer matrix honeycomb is the absorption spectrum for electromagnetic radiation in the microwave region. The transparency to such radiation may be enhanced by selection of the particular polymer, i.e., the polyimides; and by selection of the fiber reinforcement, i.e., high strength polyethylene or quartz. Inclusion of metal flakes or powders, iron oxides or metal coated fibers

may also modify electromagnetic behavior. Finally, adjustment of the honeycomb core size to cause destructive interference of particular wavelengths will cause rapid attenuation of such radiation.

In order to utilize honeycomb materials to their best advantage in radar-sensitive applications or other more prosaic applications, it is frequently necessary to produce a part which is contoured as opposed to a flat honeycomb "sandwich." An example of such an application is an airfoil leading edge.

In the past, polymer matrix honeycomb has been produced laboriously by hand layup followed by batch consolidation into a honeycomb "block." This honeycomb block could then be sliced into flat sections which were bonded adhesively between facing sheets to form lightweight, rigid panels. However, the slitting process is expensive, time consuming and entails a relatively large amount of waste. For example, with honeycomb of thin cell wall thickness, the honeycomb must first be filled with polyethylene glycol wax or a similar substance to support the cell walls during the cutting operation. This substance must then be completely removed in order that the core may be adhesively bonded to the facing sheets. When saws are used to cut through the honeycomb, the material in the kerf area is wasted, thus limiting the amount of honeycomb material which can be prepared from a given size block.

The same procedures must be followed when contoured shapes must be produced except that the amount of waste is generally considerably higher, and the cutting operation must be performed by expensive three dimensional computer controlled cutting equipment. The time consuming, waste intensive, and expensive machining operations has limited the use of honeycomb material in contoured applications. Parts which are produced for such applications are extremely expensive.

U.S. Patent 3,356,555 to Jackson discloses a batch method of preparing honeycomb core wherein a squirrel cage roller containing hexagonal bars operates in conjunction with a plurality of hexagonal major bars on a fixed bed to provide a corrugated web by the action of compressing a heated thermoplastic web between the advancing squirrel cage bars and the fixed bed bars. The corrugated webs thus produced are then assembled into a honeycomb structure by placing a first corrugated web on the major bars of a bed followed by placing minor bars in the nodes above the web. A second corrugated sheet is then located with its nodes adjacent to the first web's antinodes. An additional layer of minor bars is placed on top and the procedure repeated until the desired honeycomb thickness is achieved. The assembly is then placed between caul plates and platens and heated to form a finished honeycomb product.

In GB-A-2 188 866, a batchwise method of preparing thermoplastic honeycomb is disclosed wherein shaped formers as disclosed by Jackson in U.S. 3,356,555 are disposed between adjacent corrugated thermoplastic sheets, the assembly pressurized, and heated to cause the thermoplastic to fuse. Following the preparation of one multiple cell honeycomb segment by such batchwise operation, the section may be advanced to allow a further section to be laid up and fused. The process described requires pressurizing and heating the entire newly formed honeycomb structure.

The related art processes produce honeycomb cores in batchwise fashion requiring lengthy heating and cooling cycles to process the honeycomb, or by expansion methods which are directed to but limited honeycomb sizes and to honeycombs not having optimal properties. The processes of Jackson '555 and Great Britain '866 require the use of numerous layers of expensive metal formers. For example, a four foot length of 0.125 cell width honeycomb having but a height of four cells would

require in excess of 1400 metal formers. Furthermore, such batchwise processes are time consuming, and require pressurizing an entire honeycomb structure to enable thermoplastic fusion and adherence.

Furthermore, because the abutting node and antinode surfaces of web material is double the thickness of the non-abutting surface, this thickness disparity creates a displacement error in assembling honeycombs using metal formers. Because the error is magnified by each successive cell layer, it is virtually impossible to keep such cores aligned during layup and during cure under pressure. If the formers are made unsymmetrical, i.e. a flattened hexagon, then layup is facilitated, but distortion still occurs during consolidation as the double thickness abutting layers are compressed during fusion to approximately 80 percent of their initial thickness. Honeycomb prepared by all these processes must be cut and/or machined to produce honeycomb parts of other then planar shape.

In the parlance of one skilled in the art of honeycomb production and usage, the thickness of the honeycomb is considered as the dimension parallel to the corrugations, the length is the direction along the same surface as the corrugations but at a right angle thereto, and the width is the direction across the cells perpendicular to the plane of the corrugations (thickness and length directions).

Objects of the Invention

It would be desirable to be able to produce honeycomb materials which could be used to prepare flat panels or contoured parts without the use of wax-type cell fillers and without the use of expensive machining equipment. These and other objects have been met by a honeycomb production process wherein during the continuous preparation of thermoplastic honeycomb, the thermoplastic web is first cut or slit prior to layup along a predetermined path, the honeycomb block

prepared, and then separated along a surface determined by the cuts in successive layers.

Brief Description of the Drawings

Figure 1 - A drawing of the honeycomb forming bed with primary formers inserted and secondary formers partially inserted.

Figures 2A-2C Side views of the bed showing the ends of the primary and secondary formers with topmost and penultimate layers of fiber reinforced corrugated layers in node to antinode contact and production of honeycomb one half cell layer at a time.

Figure 3 - A side view of a bed showing a hot shoe used to achieve selective heating.

Figure 4 - A side view showing the use of a toothed wheel for achieving pressurized fusion of node to antinode contact areas with integrated corrugation of fiber web by hot air impingement.

Figure 5 - Various geometric corrugation configurations which may be used to prepare honeycomb.

Figure 6 - Isometric view of one configuration of hot shoe or platen selective heating means.

Figure 7 - Isometric view of one configuration of hot gas impingement heating means.

Figures 8A-8B Alternative geometries of 4 and 5 toothed corrugation and/or consolidation rollers.

Figure 9 - Double toothed-roller embodiment

showing second roller further consolidating the web.

Figure 10A - Two roller embodiment allowing bidirectional corrugation/consolidation with wrapover at end of the bed.

Figure 10B - The two roller method of Figure 11 showing roller assembly rotation.

Figure 10C - The two roller method of Figure 11 at the beginning of reverse travel.

Figures 11A-11B Illustrates more closely the web to web relationship in the top honeycomb layer and the difference between unconsolidated and consolidated web thicknesses.

Figure 12 - Another configuration of hot gas heating means.

Figure 13 - A honeycomb containing embedded shapes and illustrating the slitting of the web prior to layup.

Figure 14 - Web slitting in successive layers needed to form a shape having a triangular cross-section.

Figure 15 - The shapes resulting from the honeycomb of Figure 13 after splitting apart by hand.

The continuous layer-by-layer production of honeycomb material is described in detail hereafter. In order to prepare contoured or planar separable objects within a single honeycomb block, the thermoplastic web must first be slit prior to layup. Each successive layer may be slit along the same path or may be slit along different paths, thus generating planar, curvilinear or truly three dimensional complex shapes. Examples of complex shapes which may be produced are illustrated by Figures 13, 14 and 15.

The thermoplastic web, with or without fibrous

reinforcement, is preferably laid down by the method depicted in Figures 1, 4 and 10A-C, but other sequential methods as described herein are also suitable. Slitting of the thermoplastic web may be accomplished by numerous methods, for example through the use of knives, water or air jets or laser beams. The position of the knife or other slitting means may be fixed in position, or may be controlled mechanically, for example by electric servo motors or pneumatic cylinders. While the web is described as being slit from one integral web, the spirit of the invention also includes the use of numerous narrower webs which abut each other and which may be prepared by previously slitting a single web or by use of webs which were manufactured to the desired width. In the formation of three dimensional objects, computer control of the slitting means is desirable. Such methods of control are well known to those skilled in the art of computer controlled positioning equipment.

The process for preparing the honeycomb of the subject invention is a continuous process whereby (a) a first set of metal formers of suitable shape are disposed such that one former is located within each cell of the topmost layer of a honeycomb structure of at least one cell thickness, (b) a second set of metal formers displaced laterally from the first set by half the cell spatial frequency are disposed in the antinode depressions located at the top surface of the honeycomb, (c) a corrugated web of thermoplastic is laid atop of the topmost set of metal formers such that the bottom surface of the antinodes of the corrugated web abut the top surface of the nodes of the honeycomb, (d) prior to layup of the thermoplastic web (c), the web is first cut or slit by suitable slitting means along a predetermined path, (e) the node-antinode surfaces, or demes, are fused by selective heating means of these surfaces, (f) the lowermost set of formers is withdrawn from the core, raised by an amount sufficient to clear the thickness of

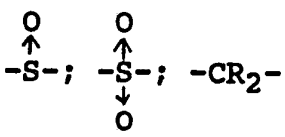
the fused node-to-antinode surface of the newly formed honeycomb cells, and disposed in the nodal depressions along the top surface of the honeycomb, becoming by virtue of this displacement the topmost set of formers; (g) a further corrugated web of slit or non-slit thermoplastic is laid atop the topmost metal formers such that the bottom surface of the antinodes of the corrugated web abut the top surface of the nodes of the honeycomb, (h) the abutting node-antinode surfaces are fused by selective heating of these surfaces, (i) steps (f) - (h) are repeated until the desired honeycomb width, which may be essentially infinite, is obtained, and (i) the honeycomb removed from the honeycomb forming machinery and separated into predetermined three dimensional honeycomb shapes.

By means of the subject invention, honeycombs of virtually any dimensions may be obtained in a continuous, cost-effective manner, without the drawbacks associated with batchwise operations, e.g., the use of multitudinous bars or formers and the time-consuming batch fusing step which must be accomplished by pressurizing the entire honeycomb core assembly or portion thereof. A single honeycomb thus formed may be easily split into planar honeycombs of predetermined thicknesses, or into complex and/or contoured parts which may be nested to maximize efficient use of honeycomb-forming raw materials.

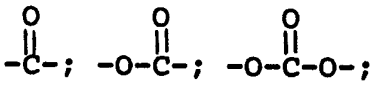
The thermoplastic matrix sheets useful in preparing corrugated sheets and ultimately the final honeycomb product contain a thermoplastic, preferably an engineering thermoplastic, and optionally fibrous reinforcement.

Among the thermoplastics useful are the various polyesters, for example polyethylene terephthalate and polybutylene terephthalate; the aliphatic polyamides, for example nylon 6, nylon 66, nylon 4, nylon 12, and nylon 612 among others; the all

aromatic polyamides or aramids, for example those produced under the trade name Kevlar®; mixed aliphatic/aromatic polyamides; polyalkylene polymers, for example polypropylene and polyethylene; the polyoxyalkylenes, for example polyoxymethylene polymers; the polyphenylene oxides; the polyphenylene sulfides; the various polyarylene polymers having interspersed between the arylene groups connecting groups such as -O-;



where R is a C^1-C^{10} alkyl or aryl group or hydrogen;



and the like, particularly polysulfones, polyethersulfones, polyetherketones, polyetheretherketones, polyetherketoneketones and other variants; and thermoplastic polyimides, including those polyimides which are thermoplastic initially but cure to form crosslinked structures at higher temperatures.

This foregoing list of thermoplastics is meant to be illustrative, and not limiting. Also useful, in this respect, are mixtures of thermoplastics, as well as mixtures of thermoplastics with a minor quantity, i.e., not more than about 20-30 weight percent of one or more thermosetting monomers, for example bismaleimides, epoxy resins, and cyanate ester resins. In the case where mixtures of thermoplastics and thermosetting resins are used, it may be necessary to effect a final heat treatment of the honeycomb, which may be continuous as by means of passing the honeycomb through a heated zone on a conveyor belt. The temperature required to cure the thermosetting resin is generally considerably less than the fusion temperature of the thermoplastic, and thus no distortion of the honeycomb would be expected.

The reinforcing fibers useful in preparing the

subject invention honeycomb may be selected from any fibers which retain sufficient mechanical properties at the processing temperatures required for fusion of the thermoplastic. Thus when low melting point thermoplastics such as polypropylene or polyethylene terephthalate are utilized, fibers of high temperature thermoplastics, i.e., aramid, polysulfone, or polytherketone may be utilized. However, preferred reinforcing fibers are those of glass, quartz, carbon, silicon carbide, and the like.

The reinforcing fibers may be utilized in many different forms. For example, random mats of staple fibers, which optionally may be needled in a needle or felting loom, may be utilized, as may mats of swirled continuous fibers. However, it is preferable to utilize reinforcing fibers in the form of unidirectional tapes or as woven fabric. Moreover, it is possible, within the same thermoplastic impregnated corrugated sheet, to utilize two or more layers of different fiber forms. For example a unidirectional tape may be sandwiched between two woven fabrics to provide greater strength in the tape fiber direction; or two woven fabrics may be oriented at a 45° angle to each other to provide a nearly isotropic assembly. By these expedients, the tensile and compressive strength may be tailored for the particular application. In a like manner, the impact resistance and electromagnetic properties may be altered by employing layers of dissimilar fiber materials, for example layers of fiberglass and carbon fibers and/or powder.

The fiber reinforced thermoplastic sheets used to prepare the honeycomb materials of the subject invention are prepared by impregnating one or more layers of fiber reinforcement with the thermoplastic, mixture of thermoplastics, or mixtures of thermoplastic(s) and thermosetting resins. Suitable methods of impregnation are well known to those skilled

in the art. For example, melt impregnation is particularly useful for thermoplastics with low fusion or glass transition temperatures, although the technique has been used with high melting thermoplastics as well. Melt impregnation is particularly successful with thermoplastics with low melt viscosities and is virtually mandatory with thermoplastics which have limited solubility. Solution impregnation, where the thermoplastic is soluble, is also utilized. In either case, the thermoplastic/fiber contents can be varied over a wide range. Preferably, the fiber content lies between 20 and 80 weight percent, more preferably between 30 and 70 weight percent, and most preferably between 60 and 70 percent. However, because of the selective heating aspects of the subject invention, sheets having exceptionally low fiber content, 100% thermoplastic fiber content, or even no fiber content may be used. The thickness of the fiber-reinforced thermoplastic sheet, or web, generally lies between 0.001 inch and 0.010 inch. Non-reinforced thermoplastic sheets, which can also be used in the subject process, may have the same thicknesses.

Honeycomb may also be prepared from 100% thermoplastic web material. These materials may consist of oriented or non-oriented continuous or chopped thermoplastic fibers, for example of polyethylene, polypropylene, or polyester. Examples of such webs are Typar® and Tekton® polypropylene spunbonded web and Reemay® spunbonded polyester web available from Reemay Incorporated, Old Hickory, TN; and Tyvek® spunbonded olefin high density polyethylene web available from DuPont. These materials, upon consolidation, may melt completely forming a solid thermoplastic web, or only some fibers may melt, forming a thermoplastic matrix containing thermoplastic fibers. The latter condition may also be realized when all thermoplastic spunbonded materials containing two different thermoplastics, for

example polyethylene and polypropylene, or a single family of thermoplastics having different melt temperatures are used.

Webs such as 100% spunbonded and calendared webs can be described as a 100% fibrous medium (where all the fibers are usually made from the same resin type) which when made up from extremely fine filament diameters, and calendared, becomes essentially impervious to fluid or gas flow. Therefore, in this process, they act as if they are made from a consolidated fiber/matrix composite or 100% resin film web and hence are able to be processed in a fashion similar to these one and two component webs described elsewhere in the application. They will melt along their bonding surfaces and thus can be joined together but retain their highly densified fibrous nature outside of the immediate area of bonding.

In preparing the honeycomb of the subject invention, the fiber reinforced thermoplastic sheet must be corrugated into a configuration which represents a half cell of the finished honeycomb. Figure 5 illustrates three different half cell corrugation configurations. In 5A, the cell shape will be square or rectangular, depending upon the depth of the corrugations. In 5B, the corrugations are sinusoidal, forming a cell shape similar to base to base bells. In 5C, the half cell corrugation is trapezoidal, forming the most preferred hexagonal cell structure. In the remainder of the specification, the description of the process and of the apparatus utilized in the process will be directed to forming a honeycomb with a hexagonal cell structure. However, the modifications necessary to provide honeycomb of other cell shapes will be readily apparent to those skilled in the art.

The fiber-reinforced and non-fiber-reinforced sheets may be corrugated by conventional means, for example by compressing hot sheets between meshing

toothed wheels as described in U.S. Patent 3,356,555 and the copending parent application. Other methods, well known to those skilled in the art, may also be used. The corrugated sheets may be prepared in the form of a continuous ribbon whose width is equal to the thickness of the honeycomb core, or may be prepared as individual sheets whose length and width correspond to the honeycomb length and thickness, respectively. Of course, the sheet may be supplied in sizes larger than honeycomb dimensions and cut to shape, but this is wasteful of both time and material.

The corrugated sheets, in whatever form, may be corrugated long before use, or may be corrugated immediately prior to layup into honeycomb in an integrated manufacturing process. Corrugated fiber-reinforced thermoplastic sheets containing low modulus fibers such as high temperature thermoplastic or glass may be prepared in roll form and used subsequently. However, with carbon fiber and silicon carbide fibers, the modulus is so high that substantial bending is not possible, and thus these materials must be prepared ahead of time in sheet form, or alternatively, integrated into the process by corrugating just prior to or coincidentally with laying up into the honeycomb structure.

With reference to Figure 1, the lowermost formers (1) which, for a hexagonal cell honeycomb, have a hexagonal cross-section, and which are secured by securing blocks (2), are inserted through the to layer of cells of a preformed honeycomb starter onto the bed rails (3). Means of insertion may be by electric servo motor, by pneumatic or hydraulic motors or rams, or other equivalent means. Topmost formers (4) are then inserted on top of the honeycomb with the formers occupying the antinode depressions in the top of the honeycomb core. Means for moving the rods (formers) and for raising and lowering them will readily suggest

themselves to one skilled in the machinery arts. Further description of suitable methods may be found, for example, in U.S. Patent 3,283,118 which is herein incorporated by reference. A corrugated sheet (not shown for clarity) is laid on top of the topmost rods such that the antinodes of the second sheet are in contact with the nodes of the honeycomb topmost layer. At least the node to antinode surfaces (demes) of the first and second sheets are heated, and pressure exerted to fuse the node to antinode surface. The lowermost set of formers are then withdrawn, raised, and inserted into the antinode depressions of the newly formed top row of honeycomb cells, becoming the topmost set of formers in the process. As a result, the honeycomb has been increased in size by one half cell height, or one entire completed cell row.

Further with reference to Figure 1, the height of both sets of metal formers (1 and 4) may be adjusted by raising or lowering the height of the bed frame (5). Various means may be used to accomplish such raising or lowering, such as the use of hydraulic or pneumatic pistons (6). The former securing blocks may be free floating, may be hinged, but preferably are regulated in their motion through the use of linear bearings (7) attached to pillar blocks (8). Other equivalent means of raising and/or lowering the formers will readily suggest themselves to one skilled in the art.

After the topmost corrugation has been fused to the existing honeycomb, the lowermost bars (1) as previously stated, are withdrawn, raised by pistons (6) to a height such that the bars may clear the thickness of the most recently fused node-antinode surfaces, and reinserted, becoming the topmost formers in the process. Both bed frames are then lowered by one half cell height and the now topmost bars lowered slightly to establish pressure between the two sets of formers and the honeycomb material located between them. The raising

and lowering sequence may be varied as long as the final result is the same or its equivalent. In Figure 1, consolidation is by toothed roller (9) and hot air heating means (not shown).

The honeycomb forming sequence is shown by Figures 2A - 2C, which are a section taken through Figure 1, but with honeycomb material in place. In Figure 2A at (1) are the lower most row of bars or formers which are located in the topmost cell layer of a honeycomb (2). The topmost row of formers (4) is inserted into the antinode depressions and clamped down trapping the honeycomb (2) between the lower (1) and topmost (4) formers. A layer of corrugated fiber reinforced thermoplastic web or corrugated unreinforced web (3) is laid atop the topmost bars (4) and consolidated at the node-antinode depression demes (5). The lowermost formers (1) are then withdrawn, raised by an amount equal to or greater than the consolidated node-antinode deme thickness and reinserted, resulting in Figure 2B.

In Figure 2B, the numbering of Figure 2A has been retained. Note that the lowermost formers (1) of Figure 2A have become the uppermost formers (1) of Figure 2B while the uppermost formers (4) of Figure 2A are now the lowermost formers (4) of Figure 2B and the honeycomb (2) has been increased in width by one half cell. Another layer of corrugated web is laid down, consolidated with heat and pressure, and the lowermost formers (4) withdrawn, elevated and reinserted, once again becoming the topmost formers (4) in Figure 2C (as also in Figure 2A), but note that the honeycomb structure (2) in Figure 2C has now been increased in width by a full cell. This process is repeated until a honeycomb of the desired width is created.

In the practice of the subject invention according to the previous description, it is necessary to heat the node to antinode surfaces and to apply

pressure to cause these surfaces to melt and diffuse into each other forming a strong bond. This process may be assisted in some cases by depositing a suitable film adhesive on the node and antinode facing surfaces; however, this approach is generally undesirable as it requires additional steps and material. Many equivalent means of heating and melt fusing the node to antinode contact surfaces may be readily envisioned, but it is preferable to fuse more than one deme at the same time. One such means, a hot shoe, is depicted in Figures 3 and 6. With reference to Figure 3, the hot shoe (4) is positioned such that the projections (2) on the bottom of the hot shoe correspond to the antinode hollows (1) on the top fiber reinforced thermoplastic or nonreinforced thermoplastic corrugated sheet. The hot shoe is wiped across the honeycomb in a direction parallel with the corrugations, that is across the thickness direction. The bottom surface of the hot shoe, which may be made of metal, ceramic, graphite, or other material, has projections (2) on the bottom whose shape and spatial frequency coincide with the cell shape and width of the honeycomb. The width of the hot shoe preferably coincides with the length of the honeycomb to be produced, as such size permits fusion of an entire half cell depth of honeycomb across the length of the honeycomb in one pass of the hot shoe. However, it is also possible the utilize a hot shoe whose width is, for example, a whole fraction of the honeycomb width and to index the hot shoe such that it makes multiple passes. Alternatively, multiple hot shoes may be utilized, each of which fuses node-antinodes along a portion of the honeycomb length.

The hot shoe also contains an integral heating means sufficient to maintain the bottom surface of the hot shoe at or above the fusion temperature of the thermoplastic. This heating means may be resistance heating coils, cartridge heaters, or hot air supplied

through flexible metal tubing. Cartridge heaters are depicted in Figure 3 at (3) from the end. Figure 6 shows the hot shoe containing an air manifold. Hot air for heating, or cool air for cooling is supplied to manifold inlet (1) and distributed to heating and cooling passages (2). Mounting holes (3) are used to mount the hot shoe or platen on the assembly (not shown) used to traverse the platen across the honeycomb under pressure to effect fusion. Preferably, the longitudinally extending projections (4) are radiused across surface (5), along the honeycomb width direction, to more efficiently transfer pressure to the node-antinode contact area and to prevent resin buildup on the shoe surface. While it has not proven necessary to apply release agents to the shoe or the thermoplastic sheet surface, such coatings may be desirable in certain cases. It may also be possible to coat the surface of the projections (4) with a slippery or non-adherent coating to assist in preventing resin buildup. This technique is particularly useful with the lower fusing thermoplastics, but may present problems with thermoplastics of high melting temperatures due to the durability of the coating and its inability to adhere to the hot shoe surface at elevated temperatures. An advantage of the hot shoe method of bonding is that the hot shoe does not have to be cooled down prior to leaving the fusing area since it is removed from this area using a sliding motion.

An alternative means for fusing the node-antinode mating surfaces of the corrugated fiber-reinforced thermoplastic sheets is to utilize a heated platen. Such a platen is also illustrated by Figure 6. The ridges or projections (4) from the surface of the platen correspond to the shape and spatial frequency of the honeycomb cells. As is the case with the sliding hot shoe, the cross section may be square for cell shapes which have a flat node-antinode surface even

though the cell shape is hexagonal as there is normally no necessity to heat the non-mating surfaces of the cell (the cell walls). The heated platen is pressed onto the exposed honeycomb surface for a time and at sufficient pressure to cause fusion at the node to antinode surfaces of the corrugated thermoplastic sheets. The pressure required is often 50 psi (0.34 MPa) or greater at the node-antinode surface which translates to 45 tons of pressure on a 12" x 48" (30.5 cm x 112 cm) platen surface. This large amount of pressure creates drawbacks to the use of such platens as it requires both the platen as well as the machine and machine bed to be of substantial construction. The essential difference between the hot shoe and platen is that the platen is placed onto the honeycomb to be consolidated with generally only an up and down motion, while the hot shoe is wiped across the honeycomb with a sliding motion. Also, hot shoes are generally radiused across surface (5) of Figure 6 resulting in concave teeth which provide for less resin pickup and which can be applied to the surface to be consolidated in either a rolling motion or a sliding motion.

An additional drawback of platen fusing is that the platen must be cooled to below the thermoplastic fusion temperature before removing from the bonding surfaces as the platen is not normally removed by a sliding motion. If the temperature is too high, resin lift-off may occur. Even at lower temperatures, resin transfer may be a problem, thus use of release agents may be required. Standard release agents such as Frekote® releases may be metered or painted onto the antinode which lies atop of the node-antinode surface which is in contact with the platen projections, or may be applied to the top surface of the platen projections, for example by means of a roller or other equivalent means. Care must be taken to insure that the release coating does not contact the node

surfaces of the top layer of corrugated thermoplastic sheets which will be bonded subsequently to the antinode of the yet-to-be-positioned next sheet.

Because of the pressure to be applied by the platen, the formers present in the assembly may bend downwards, especially along the central portion most remote from the bed edges. To ensure adequate and uniform pressure along the entire honeycomb width, the surface of the platen may be machined slightly convex, as indicated previously, so as to take into account the displacement of the rods.

Because the platen must go through heating and cooling cycles, the rate at which these cycles may be performed is important from a production standpoint. For this reason, it may be advantageous to use platens constructed of monolithic graphite. Such platens are described in copending U.S. patent application Serial No. 07/513,634 filed April 24, 1990, entitled "Monolithic Graphite Press Platens and Their Use in Consolidating Fiber Reinforced Structural Materials," which is herein incorporated by reference. To protect the soft graphite surface, the graphite platen may be coated with a thin metal coating, as described in copending U.S. application serial number 07/488,932 which is also herein incorporated by reference. The graphite platens have the double advantage of higher heat transfer rates, often double that of steel platens, and further that the temperature uniformity across the platen surface is greater.

Heated tertiary formers may also be utilized, but this method presents problems with uniformly applying pressure, although a platen above the rods may be utilized to avoid this drawback. An alternative method of fusing is to supply heat to the node-antinode surface by suitable means, for example by focused infrared radiation, ultrasonic energy, laser energy or hot air, and to use one of the previously described

devices, i.e., a shoe, platen, rod, or other equivalent means merely to supply pressure. These devices may also require some heating to offset the heat transfer which will of necessity take place during the pressurized fusion. However, in this case, the heating and cooling cycles and degree of heating will be substantially less as a substantial portion of heat is applied to the node-antinode surface itself rather than being supplied solely by the shoe, platen or rod. By far the most rapid processing is obtained when only the fiber reinforced or unreinforced web itself, with its low thermal mass, is heated.

An alternative process for the preparation of thermoplastic honeycomb is illustrated by the apparatus in Figures 4, and 9-11. This method is similar to that heretofore described, however the fusion means is improved and the corrugation step may be incorporated into the process. In this preferred method, the lower most formers (7) are inserted through the topmost honeycomb cells into the bed frame as before, the topmost rods (6) inserted, and a corrugated fiber-reinforced thermoplastic sheet positioned atop the topmost rods. The corrugated sheet or web may be precorrugated or may be corrugated as it is layed down. The node-antinode mating surfaces are then selectively heated, by dielectric heating, focused infrared radiation, hot gas or other equivalent means, and the pressure required for fusion supplied by a toothed cylinder moving transverse to the direction of the corrugations (along the honeycomb length). This combination can also be used parallel to the cell direction if the web is already in place and held there by means of tertiary formers. In some instances, it may be desirable to shield the non-contact areas of the top thermoplastic sheet from the heat source by a suitable baffle with longitudinally extending slits whose spatial frequency corresponds to the node-antinode frequency and

location. This method, sans baffle, is illustrated by Figure 4. In Figure 4, toothed cylinder or wheel (1) supplies pressure to the node-antinode contact area (2) as it rolls across the honeycomb top surface. The toothed wheel preferably has a width equal to the honeycomb thickness, or a substantial fraction thereof, i.e. greater than one third the thickness dimension, preferably greater than one half the thickness dimension. Heating means (3), here a jet of hot gas, precedes the path of the cylinder. The teeth of the cylinder advantageously have a convex surface such that pressure is smoothly applied with the rolling motion. Uncorrugated web material (4) is supplied through guide (5). Corrugation and consolidation are thereby integrated into the manufacturing process. The topmost (6) and lowermost (7) formers are withdrawn and reinserted as previously described with reference to Figures 1 and 2A-2C.

Instead of a toothed cylinder, a squirrel cage cylinder having bars of the appropriate geometry may be used. However, this method suffers from the dual drawbacks that the rods may distort, particularly for honeycomb of fine cell width, and that the bars do not have the same thermal mass of the cylinder. The cylinder or cage is not heated, but rather is desired to be maintained at a sufficiently low temperature such that resin transfer is avoided. By the toothed roller method, honeycomb consolidation may take place at a speed of 15 lineal inches/sec. (38 cm/sec) or higher. Alternative geometries of 4 and 5 toothed rollers are shown in Figures 8A and 8B. An elongated plunger having the appropriate geometry and other equivalent means may be utilized as well.

In this most preferred embodiment, the thermoplastic web is corrugated and fused in one integrated step. By this method, the problems associated with handling precorrugated webs are avoided.

This is important, as it is sometimes difficult to prepare corrugated material to exact dimensions. Furthermore, it is often difficult to feed such material onto the top honeycomb surface without stretching or distorting the web and thus the node to antinode spatial relationship. In this preferred method, the thermoplastic web is supplied from a roll in an uncorrugated state. The web is laid down atop the topmost layer of honeycomb and both the honeycomb and web simultaneously heated. The web is simultaneously corrugated and fused by the trailing toothed wheel as previously described.

The use of a toothed cylinder or squirrel cage roller or its substantial equivalent is particularly useful in the subject invention, as the tension thus created on the web tends to cause the slit surfaces to butt against each other forming what appears to be an integral honeycomb, yet one which may be easily separated by hand along the surface formed by the slits in successive layers. In this process, the web is slit just prior to being corrugated by the corrugation/consolidation roller.

Figures 11A and 11B illustrate in an enlarged fashion, the consolidation process, in this case utilizing a toothed roller, the preferred method, with hot gas, microwave, or radiant heating (heating means not shown). In Figure 11A, the upper web (6) of fiber reinforced web lies atop the topmost set of rods of which (1) is the leftmost member in the drawing. The bottom web (5) lies atop the lowermost set of rods of which (2) is the leftmost member completely shown, and between the topmost and lowermost rods. The uncorrugated, one web thickness is shown at B-B. At (3) in Figure 11A is shown the consolidated web which across section A-A is generally about 80 percent of double the B-B thickness. During corrugation/consolidation, the webs are heated and corrugation/consolidation roller (9

in Figure 11B) lays down and consolidates the webs at (4 in Figure 11A). Figure 11B illustrates the degree of compaction which may vary from virtually 100% with all thermoplastic webs to 70-50 percent or less of the original two ply thickness with fiber-reinforced materials. The higher the degree of thermoplastic impregnation, the greater the anticipated degree of compaction.

Again, with reference to Figure 11B, section B-B in the unconsolidated two ply thickness while the consolidated thickness at A-A is approximately 80 percent of the B-B thickness. At (8) is shown the side wall of the honeycomb which may be substantially the same thickness as the unconsolidated web, or which may, especially in the case of the high thermoplastic content webs, be somewhat less than that thickness. The geometry of the roller may be adjusted to supply high, little, or no pressure on these side wall surfaces.

Again with reference to Figure 11A, the fully consolidated node-antinode deme is shown at (3) and the uncorrugated web (7) is simultaneously corrugated and consolidated by the roller (not shown) by heating with heating means (not shown) and being compressed between the roller (4) and the topmost set of bars (formers).

Figure 9 illustrates a secondary bonding consolidation embodiment. Trailing the path of consolidation/corrugating wheel (1) is an optional secondary fusion heat source (2) which heats the already fused node to antinode surfaces (3) for a second fusion/consolidation in order to achieve more complete bonding. Pressure for bonding is supplied by second roller (4); while heat is supplied by secondary air jet (2). The rollers are mounted in carriage (5) which, upon reaching the end of the bed of formers, is raised and traversed back to the start position after severing the end of the web. The secondary bonding technique may also be used with the continuous dual corrugating/

consolidating roller system portrayed in Figures 10A-10C. In this case, two pairs of secondary bonding wheels and secondary jets are utilized, one on the leading and one on the trailing side of the rotatable central corrugation/consolidation wheels.

Figures 10A-10C illustrate a method of forming honeycomb which eliminates traversing the toothed roller and selective heating means back to its initial starting position prior to laying down the next. In this embodiment, two hot air heating means are used. The thermoplastic web is laid down as the twin consolidation and corrugating rollers (1) and (2) pass left to right. The bottom most roller (1) performs corrugations and consolidation. Uncorrugated web (7), which may be slit as desired, is supplied through guide (8). Hot air for corrugating and fusing the web is produced by hot air jet (3) similar to that shown in Figures 7 and 12. When the advancing web reaches last former (4) at the edge of the bed, the gas flow to heating means (3) is shut off, the bottom-most row of formers is retracted, raised by an amount slightly greater than the height of the consolidated node-antinode thickness, reinserted becoming now the topmost row of formers, and lowered down onto the honeycomb, preferably exerting pressure between the honeycomb topmost layer and the lower set of formers. The carriage (5) containing the twin corrugating/consolidating rollers then rotates clockwise as depicted in Figure 10B as the rods are exchanged thus wrapping the web around the end topmost former (4 in Figure 10C). The rollers then traverse right to left with the left most air heating means (6) turned on to heat the web to the consolidation temperature. At the end of its travel, the left most hot air jet (6), is turned off, the bottom-most formers retracted, raised, inserted and clamped as before, and the consolidation wheel carriage rotated counter-clockwise to the original position. This process is repeated until the desired

honeycomb width is achieved.

Figure 10B shows the apparatus of Figure 10A in partial clockwise rotation, in this case partway down the bed rather at the end. It is possible to make any particular former the "last" former. Figure 10C shows the apparatus traversing right to left with hot air jet (6) supplying heat while jet (3) is shut off. The uncorrugated web (7) is supplied through guide (8) mediate to the two rollers (1) and (2).

Figure 12 depicts a configuration of gas impingement jet (2) which has been found to eliminate the lack of total consolidation of the node-antinode demes when used with a four or five toothed consolidation roller. With reference to Figure 12, the major hot gas delivery through tube (1) exits the jet through slit (3). Bleed holes (5) result in hot gas jets 4 which impinge upon the lower surface of the uncorrugated web being applied. The extended nozzle contains an internal baffle separating the major gas stream from the bleed stream. By use of the extended nozzle, the shadow area in the antinode depression is eliminated, resulting in complete consolidation.

Following preparation of the honeycomb, the honeycomb is split apart along the surfaces defined by the repeating layers of slit material. This operation is performed by hand and generally results in no damage to the honeycomb material. Occasionally, a sharp knife may be useful in parting certain areas of the honeycomb, but this is generally not necessary. A drawing of a completed honeycomb containing several embedded shapes is illustrated by Figure 13.

Figure 13 illustrates a block of honeycomb laid up containing a multitude of separate shapes. Letters A-O represent the successive layers of thermoplastic web which have been laid down to produce the honeycomb. Numerals 1-13 identify the various shapes being prepared. Layer A represents the last

layer in the process of being corrugated and fused to form the topmost row of honeycomb cells. For clarity and ease of drawing, only two thicknesses of cells are shown at (15) along the length direction of the core. The topmost web (A) is supplied originally in uncorrugated, slit form (14). Slits (16) are those required to form the boundaries of shapes 2, 3, and 4 in the topmost layer A. The boundaries of the other shapes which intersect the topmost layer A are shown similarly. For shapes which have boundaries not perpendicular to the honeycomb dimensions such as 1, and 8-13, the position of the slitting in successive layers 0-A will vary, the position of the slit being determined by the intersection of the shapes' boundaries with the plane of the web layer. Due to the nature of the continuous process used to form the honeycomb, the upper (17) and lower (18) cell walls will have a thickness greater than the remaining four cell walls due to the upper and lower walls being formed from two layers of web material which are fused together.

Figure 14 illustrates how the web layers 0-A must be slit to form shape 1 of Figure 13. In Figure 14, (1) is the triangular cross-section shape to be formed, while letters 0-A represent successive web layers needed to form this shape, the slits in each web being made at (2), along the intersection of the boundary of shape (1) with the web layers 0-A.

Figure 15 illustrates an exploded view of the shapes produced by the honeycomb construction and slitting schema of Figure 13. The shapes (1-13) bear the same numbering as Figure 13.

The examples below have been run with numerous fiber reinforcements, for example glass fiber webs of 108, 112, 120 and 7781 woven styles and 1 to 3 oz. non-woven webs; carbon fiber webs of collimated unidirectional tape, 282 woven style, and 0.5 to 4 oz. non-wovens; and Nomex® fibers in a Kendall style 1209

non-woven web. Tyvek® style 1085A spunbonded 100% polyphenylene web, Typar® style 3353 100% polypropylene web, and Reemay® style T-550 100% polyester web have also been used. Resins used were polyethersulfone, polyphenylene sulfide, polyetherimide, polyetheretherketone, polyetherketoneketone, ULTRASON® 2000 liquid crystal polymer, polyethylene, polypropylene, polyethylene terephthalate and nylon. Examples 1-7 illustrate the continuous production of unitary (non-separable) honeycomb while Examples 8-9 illustrate the production of honeycomb containing embedded separable shapes.

Example 1

A variety of thermoplastic fiber reinforced honeycombs were prepared with 1/8" and 1/4" cell sizes by utilizing the device shown in Figure 1 without the toothed wheel consolidation roller but with rolling and sliding hot shoes. The rolling hot shoe had a 7 inch radiused surface heated by a Watlow 2000 watt cartridge heater heated to 1000F (538C) which resulted in a contact surface temperature of 700-900F (371-482C). Pressure on the node-antinode surface varied between 80-140 psi. Bonding speed in the direction transverse to the corrugations (along the corrugations length was 2-6 inches (5-15 cm/sec.).

The sliding platens utilized varied from 1" (2.5 cm) to 6" (15cm) in the node direction. Single node-width sliding hot-shoes (sliding platens) as well as those corresponding to the width of the entire honeycomb were utilized. Transverse speed was varied as with the rolling platen described before. Platen materials utilized included stainless steel, aluminum, and monolithic graphite. Heating was by strip heaters (1000-3000 watt Watlow) which were in constant contact with the platen surface. The single node sliding platen utilized a 1/8" diameter cartridge heater wrapped with 2 mil stainless steel foil, this heating device comprising

the bottom-most surface of the platen. Heater temperatures varied from 800-1200 F (427-649C) resulting in temperatures at the web surface of from 650-850 F (343-454C). Typical pressures at the web surface were between 80 and 160 psi.

Example 2

The procedures of Example 1 were followed, but a fixed platen as in Figure 6 (no rolling or sliding motion) was utilized. Graphite and ceramic platens were the platen materials of choice since the platens must cool down before removing from the fused node-antinode demes. Rapid thermal cycling dictated a platen with low thermal mass. Strip heaters contacting the top of the platen surface proved slow to heat up (7-10 min/cycle). Typical heater temperatures were in the range of 1200-1500 F (649-816 C). The preferred heating source was an HTT Moen System of hot air impingement onto the top of the platen. The orifice size of the air jets were in the range of 0.020" (0.05 cm) to 0.100" (0.25 cm) with the ratio of the distance to platen surface/orifice size lying between 2 and 8. Compressed air at 1200-1600 F (649-871 C) was fed at a back pressure of 10-20 psig. By use of this method, cycle time of 1-4 minutes were observed with thermoplastic matrices having Tg's in the 400 F (204 C) range and melt temperatures between 650 and 800 F (343 C to 427C) such as PEEK polyetherketone or PES polyethersulfone.

Example 3

In honeycombs prepared by this example, a precorrugated sheet was layed up as in Example 1 and hot air or infrared heat used to heat the thermoplastic web. Consolidation was performed by a rolling, sliding or fixed platen as in Examples 1 and 2. A disadvantage of this method is that a clamping mechanism must be used as without it the corrugated web distorts upon heating, and the node-antinode demes are dislocated.

Example 4

The former bed of Figure 1 is utilized, with a ten tooth corrugation/consolidation roller as depicted in Figure 4. The pitch and geometry of the roller teeth is based upon the desired honeycomb geometry (former shape) taking into account the thickness of the web. Conventional design techniques were used to determine the geometry appropriate for each trial. The toothed wheel geometry used in this example is as depicted in Figure 4.

A hot air jet with geometry shown in Figure 7 was used to supply hot air to the uncorrugated thermoplastic web just prior to its corrugation/consolidation as shown in Figure 4 at 2. An ADC hot gas torch running nitrogen at a back pressure of between 50 and 100 psig and a flow rate of between 50 and 100 SCFM produced an exit gas temperature typically of from 1100-1400 F (593-760 C), and 800-900 F (427-482 C) at the web surfaces. An HTT Moen unit using compressed air was also used. The nozzle type and size is dependent upon material composition and width, but typical nozzles had a distance to web/orifice size ratio between 2 and 8.

The uncorrugated material was fed onto the honeycomb top surface with the hot air jets on and the roller running at speeds of from 1 to 20 inches/sec (2.5 to 51 cm/sec) typically from 6 to 12 inches/sec (15 to 30 cm/sec) at a pressure on the node-antinode deme of between 50 to 300 psi, typically between 80 and 160 psi. Examples of measured consolidation speeds which have been achieved are 10 inches/sec (25.4 cm/sec) with 7781 woven glass fiber/polyphenylene sulfide; 6 inches/sec (15.2 cm/sec) with 112 woven glass/polyethersulfone; and the Tyvek®, Typar and Reemay non-wovens at 15 ips (38.1 cm/sec). The width of the roller used in this example was 11.5 inches (29.2 cm).

When the roller and web reached the end of the

row of formers, the gas flow was interrupted, the web cut with a razor knife, and the roller and uncorrugated web traversed to the starting position. At this position, the lowermost rods were withdrawn, raised by a distance greater than the thickness of the consolidated node-antinode surface, reinserted, and clamped down. The process of corrugation/consolidation was then repeated until the desired honeycomb width was reached.

This process resulted in more uniform webs having more perfect cell shape. With some web materials, incomplete bonding of the node/antinode deme at the area furthest from the advancing toothed roller was noted. A change in nozzle design has alleviated this problem, for example by using the four toothed and five toothed consolidation rollers of Figures 8A and 8B with the modified gas impingement heater of Figure 12. A second fusion step as depicted in Figure 9 would also result in superior consolidation.

A 3.3 lb/ft^3, 1/4" cell honeycomb made according to this example from 108 style woven glass oriented on a $\pm 45°$ bias to the cell direction and impregnated with 35 percent by weight polyethersulfone was manufactured and tested yielding the following results:

Flatwise Compression	158 psi
Flexure	350 lbs
Plate shear	988 lbs

These values compare favorably to values for thermoset honeycomb. However the thermoplastic honeycomb requires only 1 minute to fabricate a cubic foot of honeycomb structure exclusive of top and bottom panels, while a similar thermoset honeycomb or adhesively bonded thermoplastic honeycomb requires typically greater than 24 hours to fabricate a similar size structure.

Examples 5-7

Induction bonding, ultrasonic bonding, as well

as resistance heating of the fibers and ultrasonics were attempted. All of these attempts were successful in bonding the materials together but it was difficult to achieve adequate process speed and accuracy of heating.

Induction bonding experiments were conducted using the RF source from a home microwave oven (believed to be operating at 2.5 GHz having up to 700 watts output) and a rectangular wave guide component with one end connected to the RF source and the other end potted with an RF transparent epoxy as the pressure surface/energy window. The level of power was varied as a function of resin type, web thickness and fiber type. Only lower melting resins were used such as polyethylene and nylon because of the temperature limitations of the epoxy window. Since the resins by themselves had little or no loss term associated with them, it was generally required to add a small amount of loss medium, such as carbon black or iron carbonyl powder, to the resin to enhance the susceptibility of the materials to the RF radiation. Glass reinforced systems were able to be bonded in less than two seconds/bond, however, the presence of carbon fibers in the resin usually precluded sufficient heating due to the high reflectivity of the fibers to the radiation.

Ultrasonics experiments in this area of technology utilized a 1000 watt Sonics and Materials industrial ultrasonic welding unit. These units work on the principle of converting an oscillating electrical signal into a mechanical one via a crystal convertor. The mechanical vibrations are then passed through a tuned horn of the appropriate shape. The fusion of the thermoplastic material occurs when the vibrating horn causes the two web surfaces to vibrate against one another and subsequently causes a frictional heat build up that is sufficient to melt the two materials together. Several horns were constructed (a .150" diameter face horn and a 4" x .144" face horn) and used

in the tests with amplifiers ranging from 1:1 to 1:2.5. Testing revealed that sufficient bond strength could be achieved in less than two seconds per node. Tests were performed on glass/PES, PPS and PEEK equivalents in both woven and non-woven styles. The non-reinforced resin webs bonded, on average, twice as fast as the reinforced versions. The glass reinforced systems were perhaps 25-50 percent faster than the graphite systems. The horn surface had to be in the absolutely correct position (parallel to the rod surface from one end to the other) in order to achieve uniform bonding over the entire node bond area. If this is not done, poor, irregular bonding will result. Because of the shape of the horn, this is not easily accomplished, and requires a self-aligning mounting device which will compensate for the inevitable web and rod irregularities. This difficulty then presents a potential difficulty for a multiple faced horn design because it will be difficult to guarantee a uniform web thickness or rod surface over a multiple node area. This is essentially the same problem faced by the solid platen approach described earlier which requires individual platen pressure elements to overcome. However, this fix will not work as well with ultrasonics since the horn must have intimate contact with the both the booster mating surface as well as the material for optimal energy transfer to occur. Therefore, the only approach that appears to be feasible is to use a series of single faced horns which are each driven by their own convertors. However, like the multiple platen approach, it does require a rather high level of mechanical complexity to put into effect.

Resistance heating of the fibers themselves (carbon or graphite in this case), was attempted. An AC/DC welder was used to apply various amounts of both AC and DC currents through the carbon fibers in order to heat the surrounding fibers. Heat up times were quite rapid, but it was difficult to maintain a constant level

of contact with the carbon fibers as the heating took place so that the degree of heating was difficult to control. Cycle times were less than two seconds per node but the amount of heating from node to node was quite erratic. An extension of this technique was also applied to a heating of the rod mandrels. Since the original steel rods would be difficult to heat up and cool down quickly without losing their dimensional stability, these metal rods were replaced with monolithic carbon rods supplied from Stackpole, Inc. A high current/low voltage energy source was connected to the rods as the top (already corrugated) web was applied in a rolling fashion. Because the rods had to heat to a sufficient temperature and then transfer that heat to both layers of material, the process is inherently slow, but it does work. A strip of copper conductor was used to apply the current to the rods in a sequential fashion as the top layer of web is applied. Bond times of approximately 10 seconds/node were achieved using this method. An alternative method of heating the rods was to insert small (1/8" diameter) cartridge heaters inside the carbon rods for the heat source. The drawback to this technique was the slow cycle time of the cartridge heat source. Bond times for this method average over 20 seconds/bond.

Example 8

A honeycomb block of Tyvek® 1085D spun bonded web was prepared by the method of Example 4, using apparatus similar to that depicted in Figures 1 and 4. Prior to passage of the web under the corrugation/consolidation roller, the web was slit with a number of knives. Tension on the web forced the web to butt together along the cut surface without any loss of material. After bonding many successive layers, the honeycomb block could easily be split by hand into planar honeycombs the number of which is one greater than the number of knives used. Accuracy of ±0.005

inches (±0.13 mm), the current industry standard, could be maintained.

Example 9

In a manner similar to Example 8, a three dimensional part with a leading airfoil shape was prepared by using a single knife and changing the knife position by approximately 0.100 inch (2.5 mm) prior to laying down the next layer. Laying down of twenty half cell layers resulted in a total deviation of approximately 2 inches (5 cm) in one direction, following which the knife was retracted by the same amounts in the reverse direction. The honeycomb block thus prepared was easily separated into an airfoil leading edge and the corresponding negative of the part. The knife was also moved laterally and then back to its original position during a portion of the slitting operation within each layer for several successive layers producing "dimples" or "cutouts" in the final part.

C L A I M S

1. A process for the preparation of a honeycomb part of predetermined shape, comprising

(a) disposing a first set of a metal formers into the topmost cells of a honeycomb structure having at least one row of cells;

(b) disposing a second set of metal formers, displaced by half the cell spatial frequency, in the antinode depressions in the topmost honeycomb surface;

(c) supplying a corrugated web of fiber-reinforced thermoplastic atop the topmost row of metal formers such that the antinodes of said corrugated web coincide with the exposed nodes of the topmost layer of said honeycomb structure;

(d) slitting some or all of the layers laid down in step (c) in a predetermined pattern such that following honeycomb preparation the resulting honeycomb may be separated into a honeycomb part having said predetermined shape;

(e) heating and applying pressure to at least the node-antinode demes in amounts sufficient to fuse the node-antinode surfaces;

(f) retracting the lowermost set of formers, raising said formers by an amount at least equal to the thickness of the fused node-antinode surface, and redeposing the rods in the antinode depressions in the topmost honeycomb surface becoming topmost formers by such movement, and

(g) repeating steps (a) - (f) until a honeycomb of the desired depth is obtained,

(h) separating the honeycomb structure thus formed in steps (a)-(g) along the surface(s) determined by the slit webs in successive layers into parts of said predetermined shape.

2. The process of claim 1, wherein said slitting (d) precedes the travel of said thermoplastic web under a corrugation/consolidation roller.

3. The process of claim 1 or 2, wherein a slitting means is used to slit said thermoplastic web.

4. The process of claim 3, wherein the position of said slitting means is controlled by computer generated positioning signals.

5. The process of claim 3 or 4, wherein said slitting means is selected from the group consisting of

a) knives,

b) liquid or air jets, and

c) laser beams

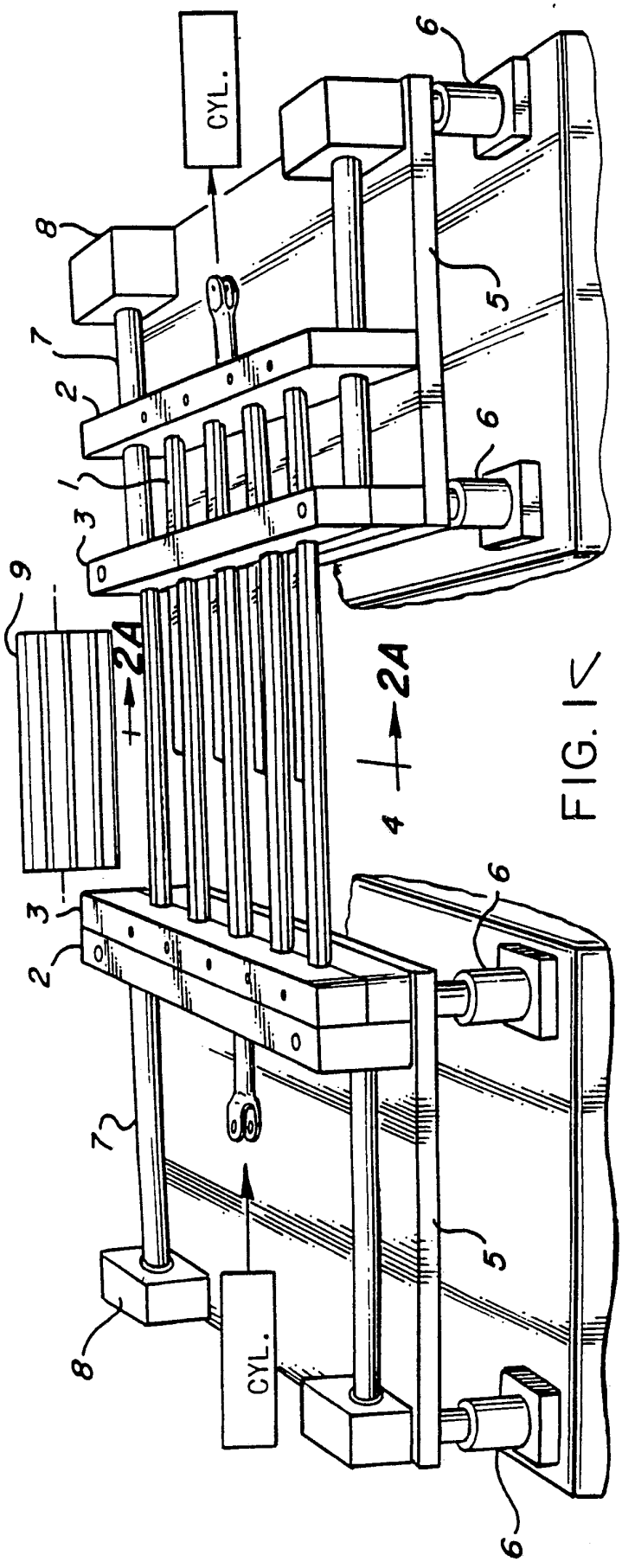


FIG. 1

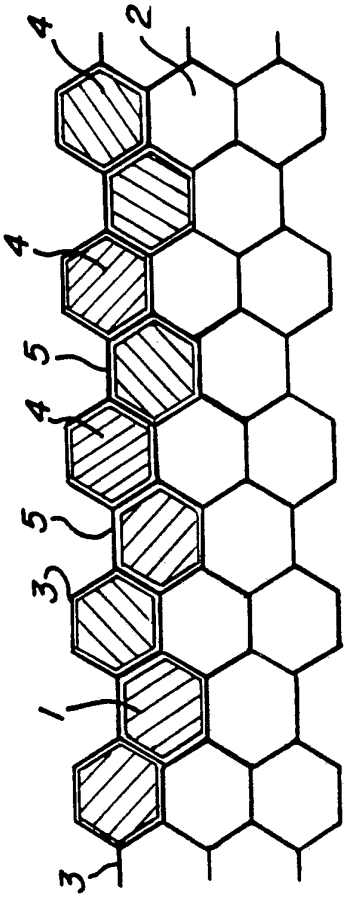


FIG. 2A

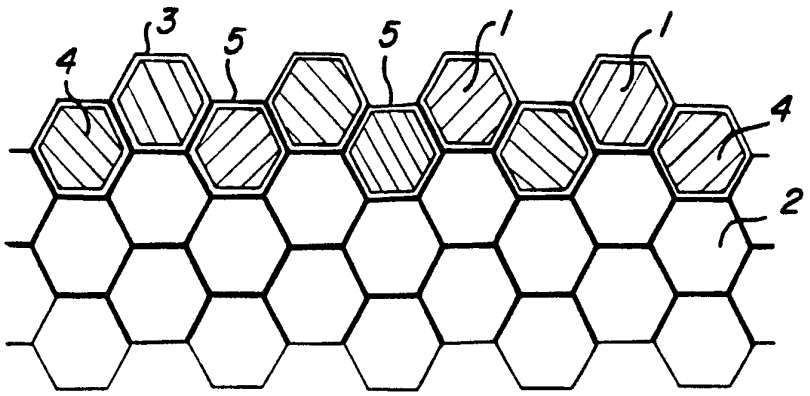


FIG. 2B

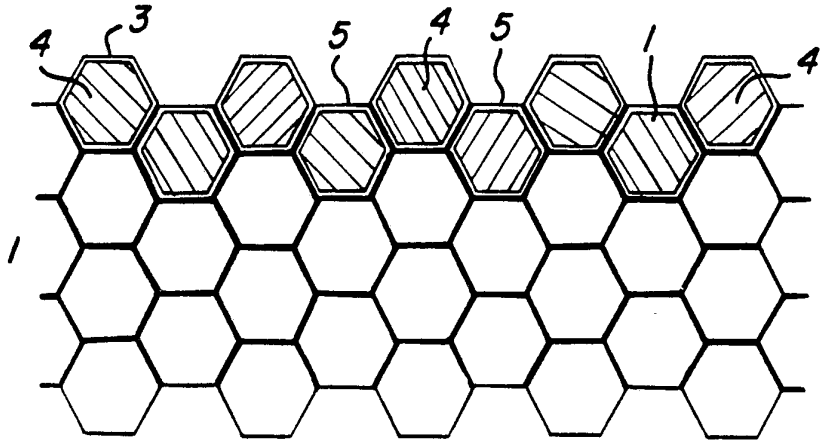


FIG. 2C

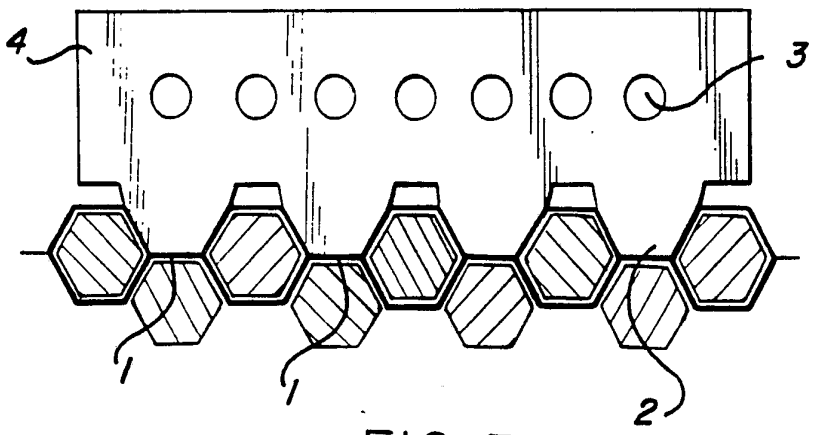


FIG. 3

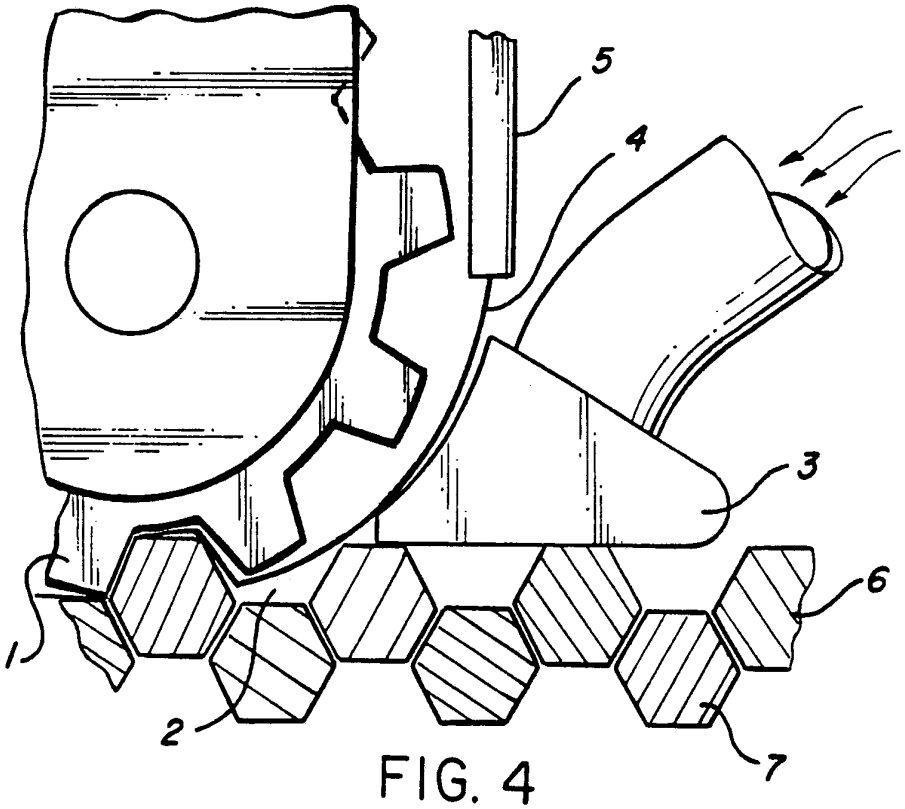


FIG. 4

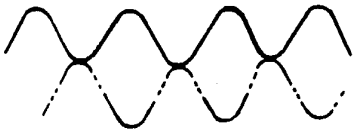


FIG. 5A

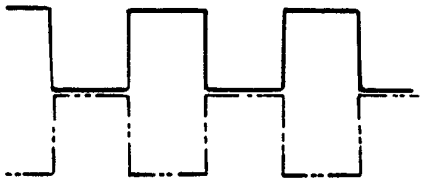


FIG. 5B

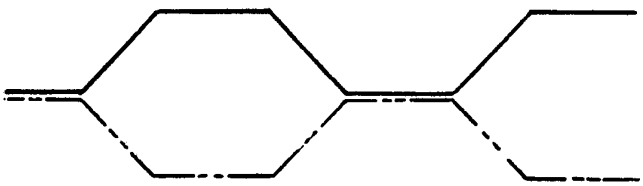


FIG. 5C

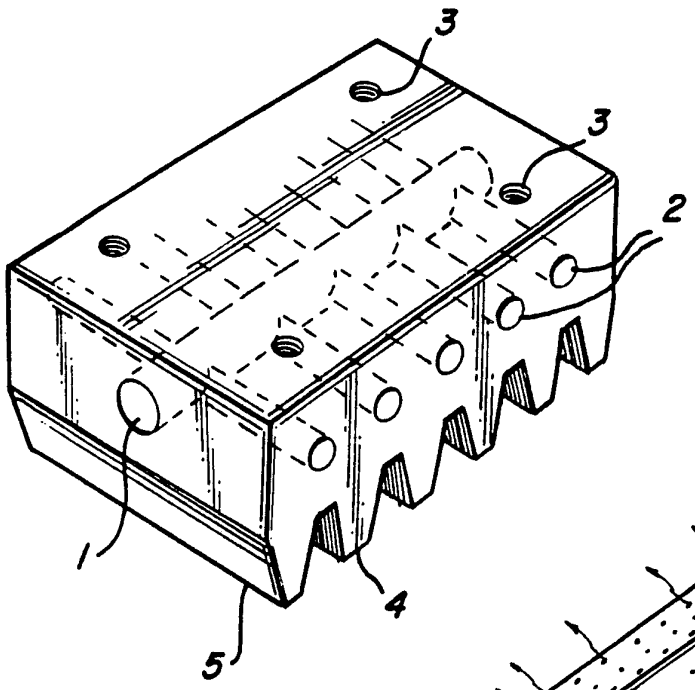


FIG. 6

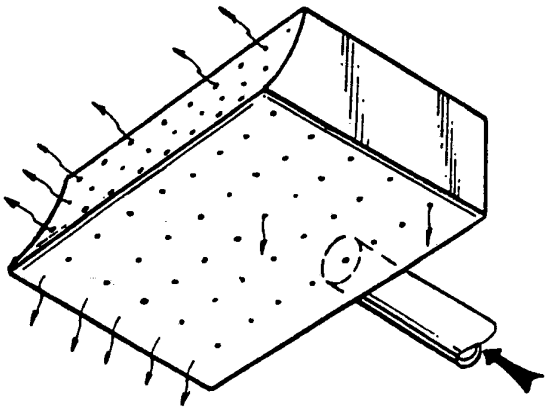


FIG. 7

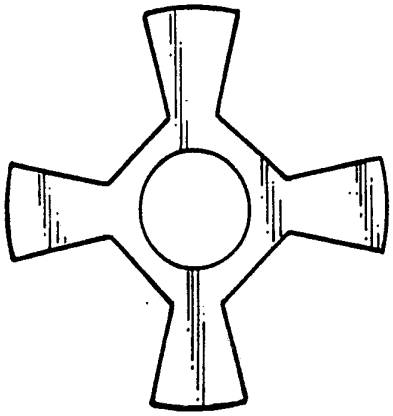


FIG. 8A

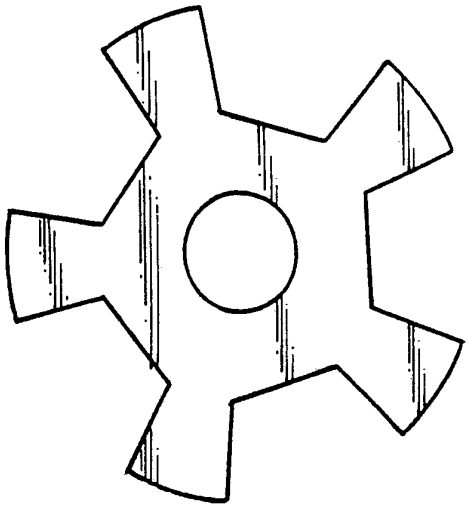


FIG. 8B

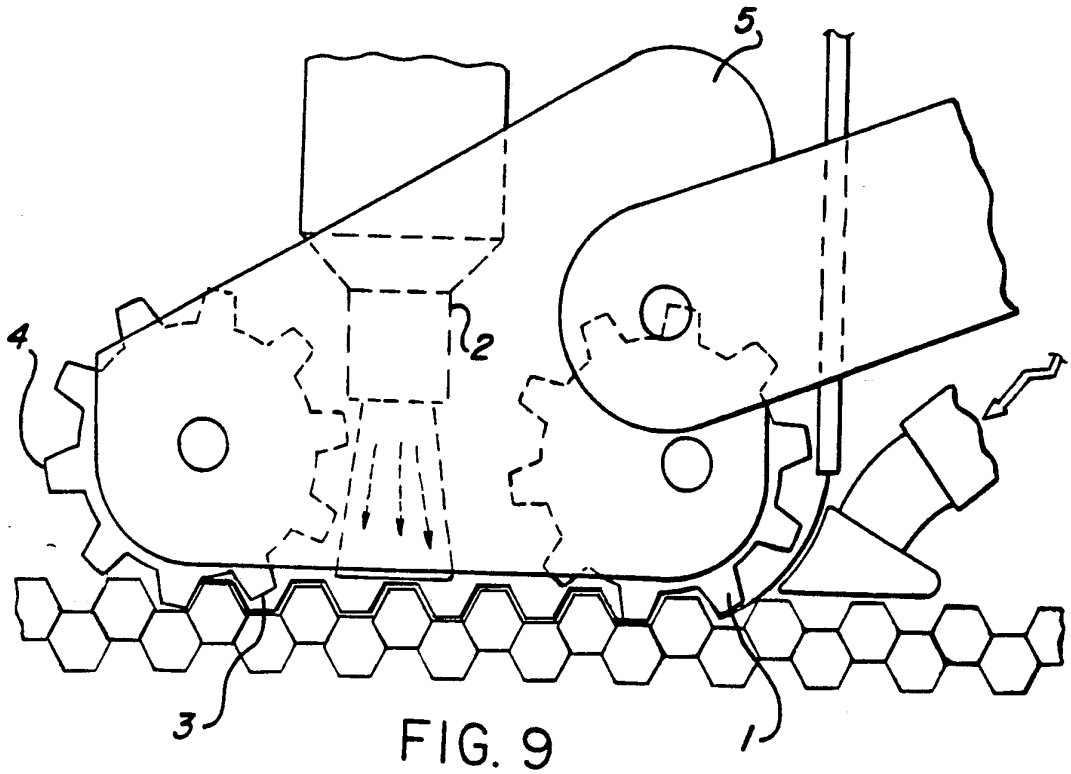


FIG. 9

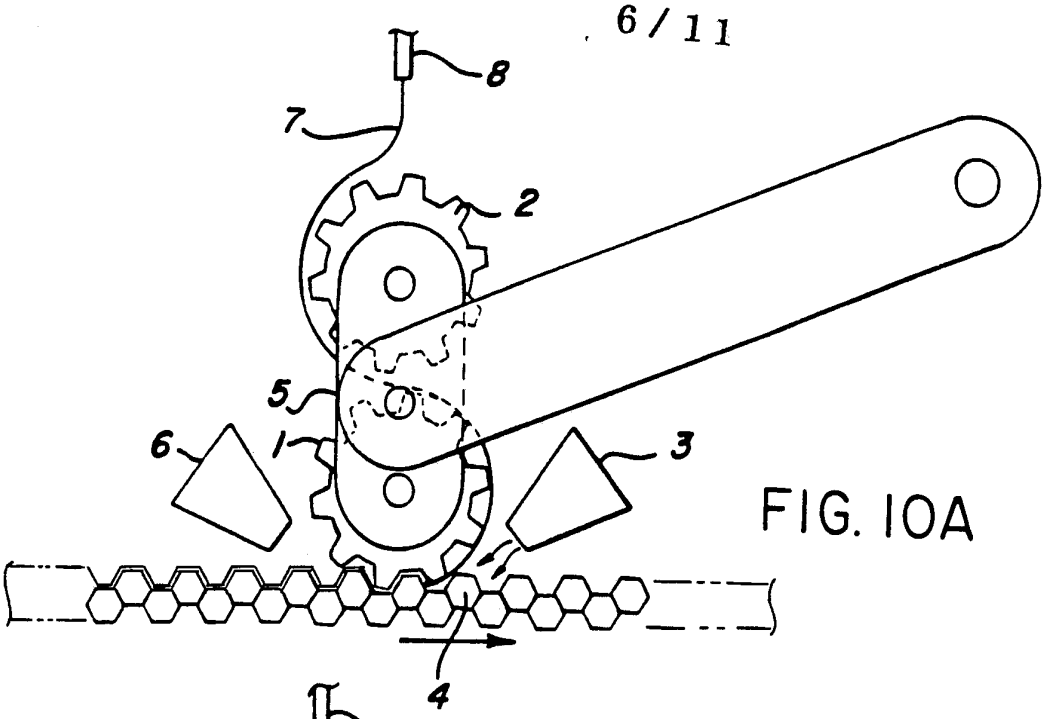


FIG. 10A

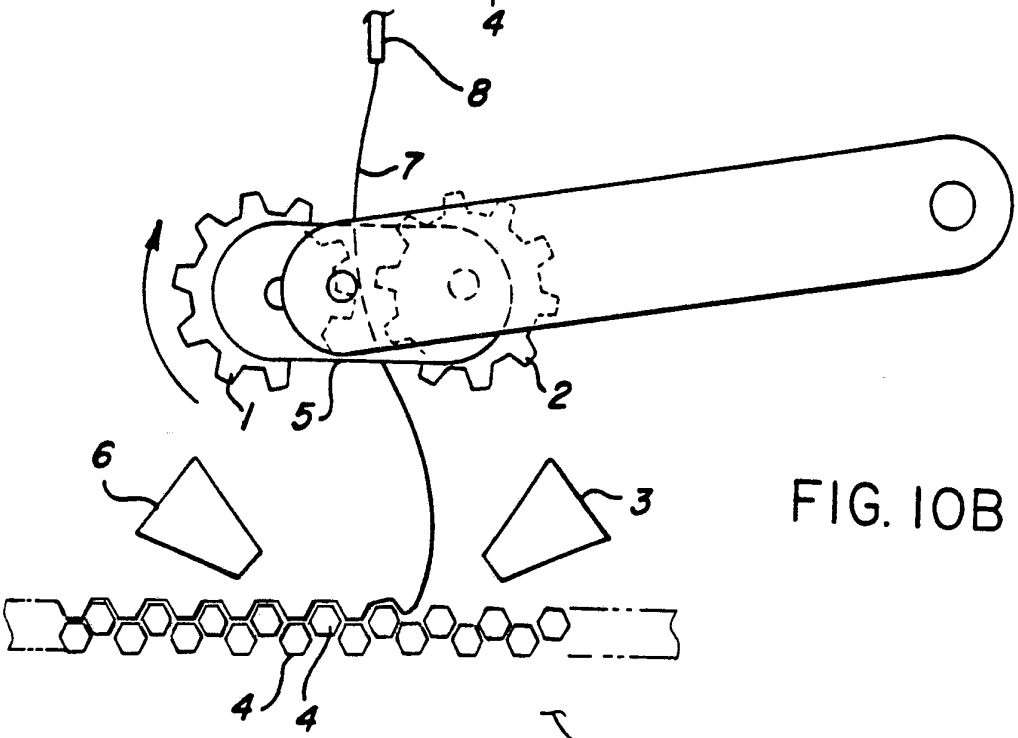


FIG. 10B

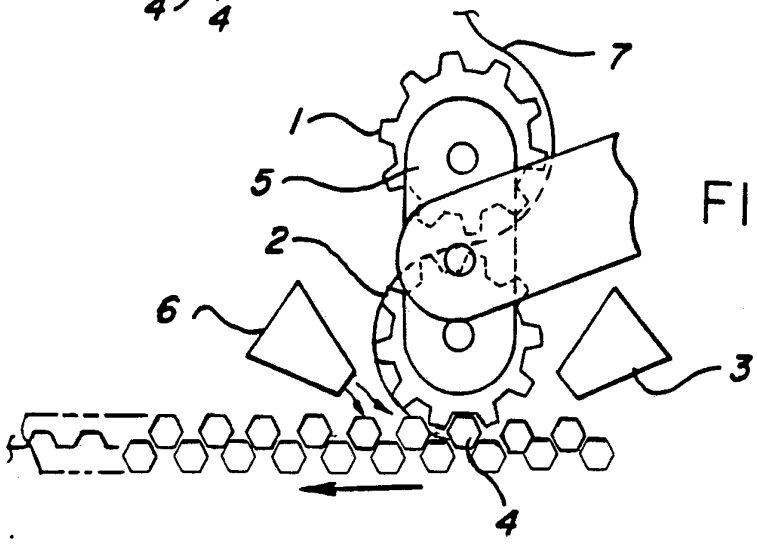


FIG. 10C

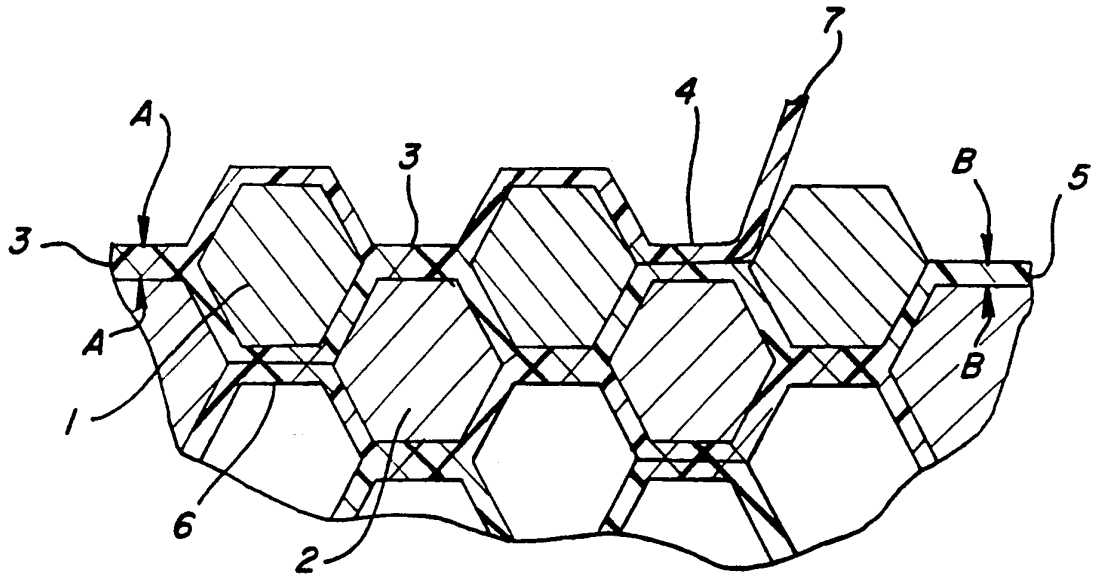


FIG. 11A

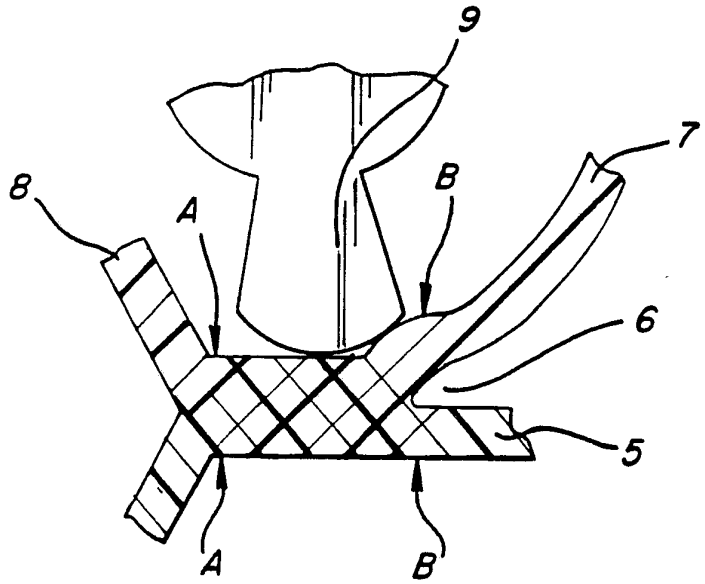


FIG. 11B

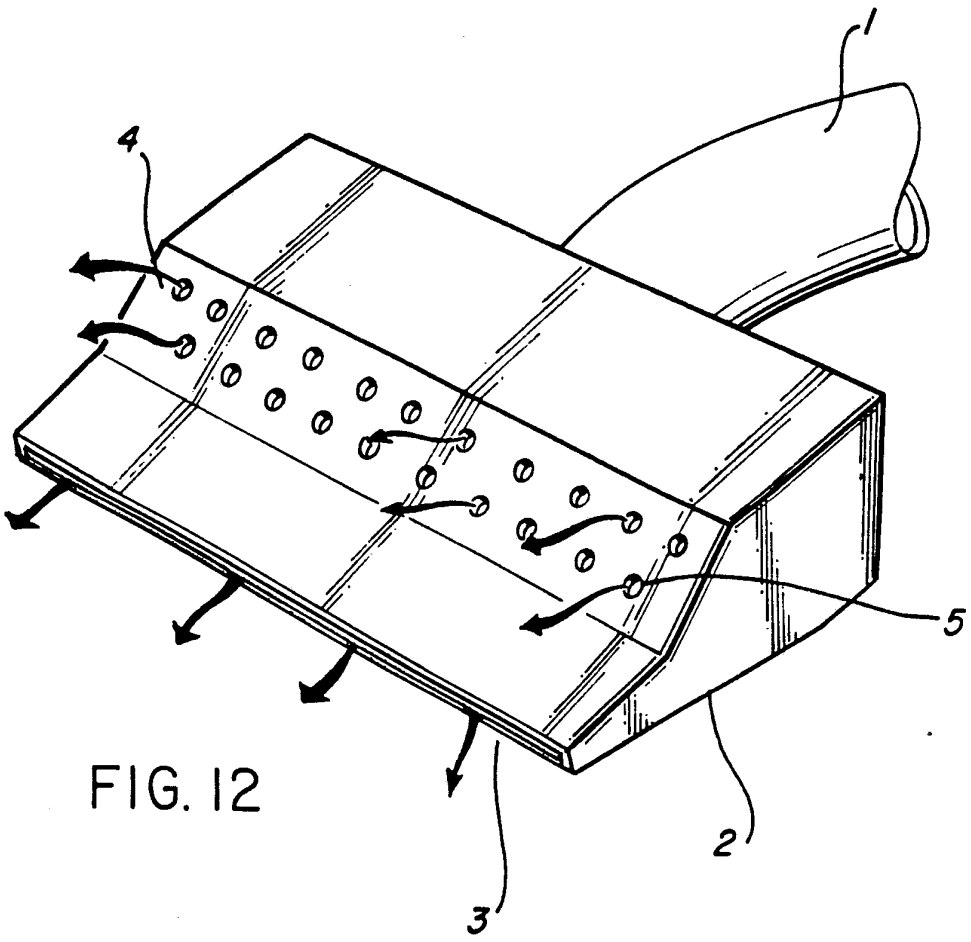


FIG. 12

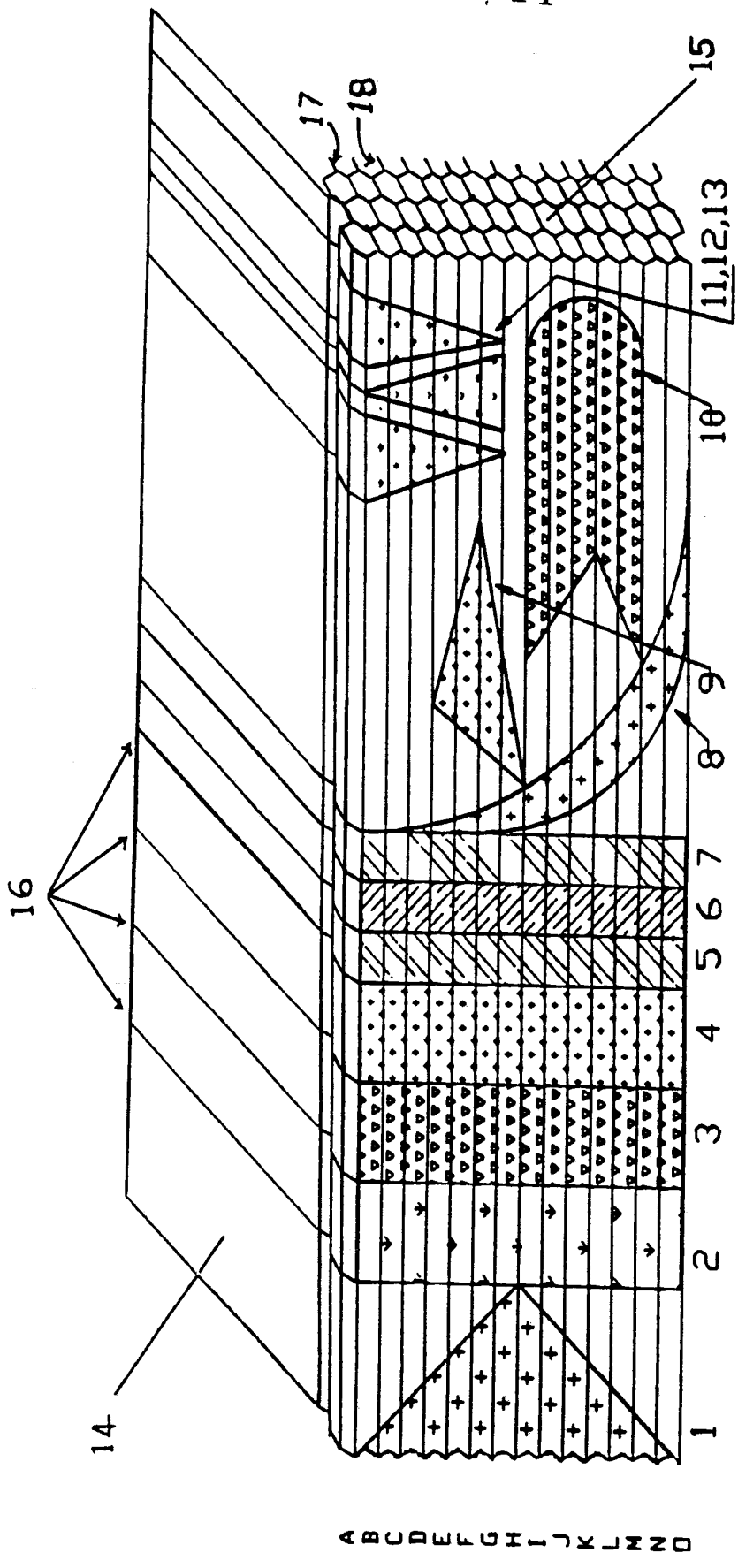


FIG. 13

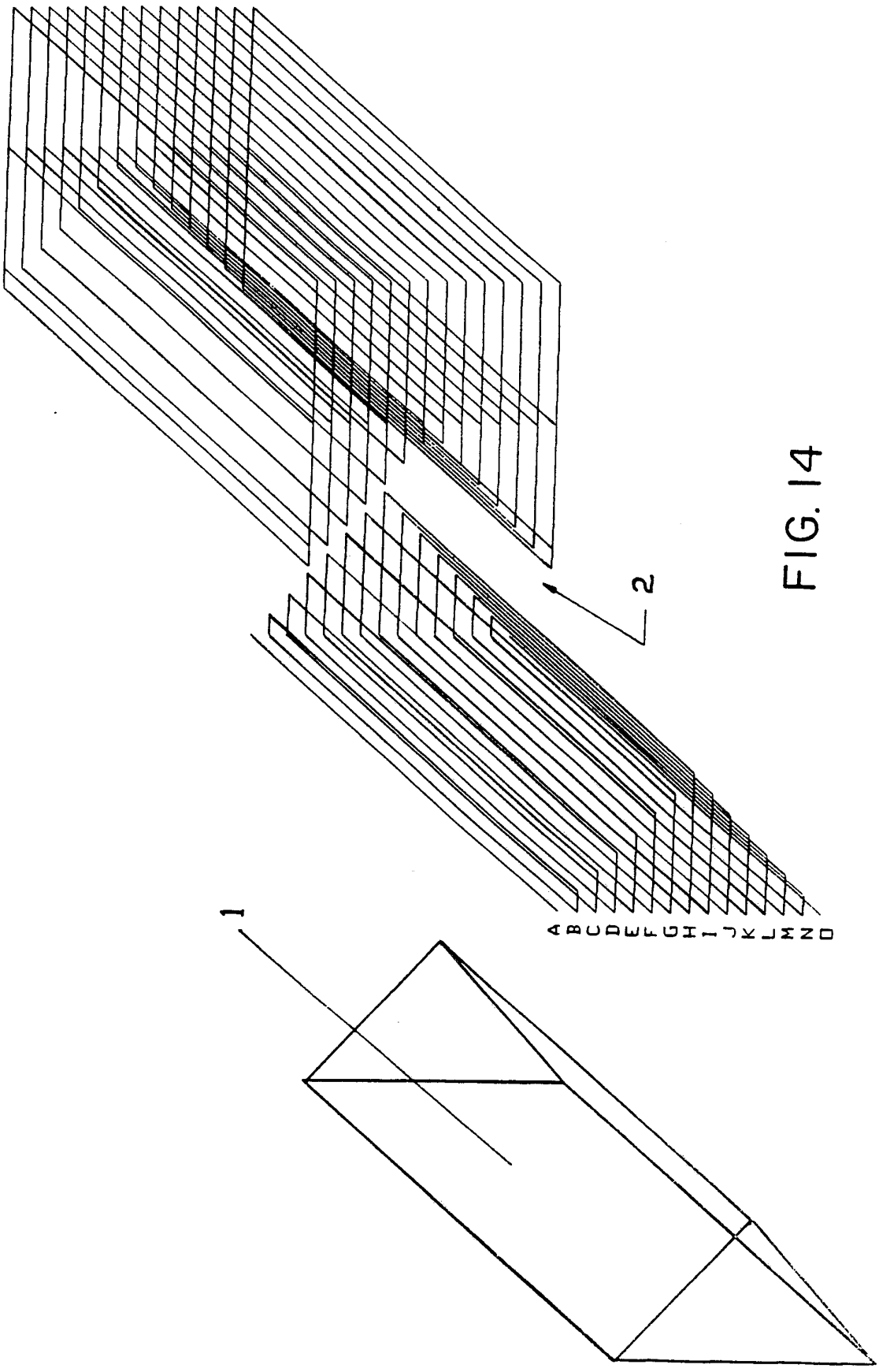


FIG. 14

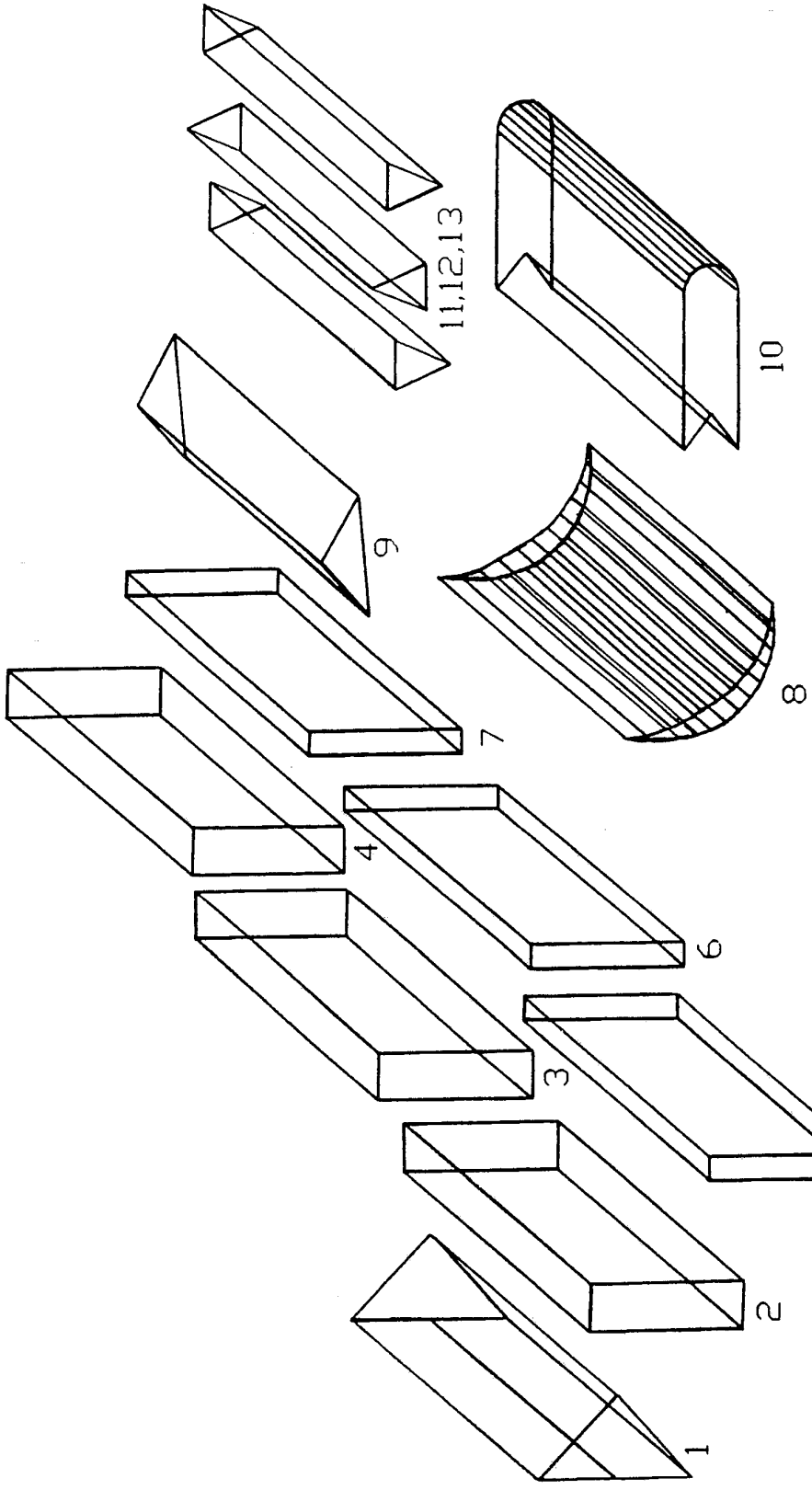


FIG. 15

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/09022

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): B32B 31/20
US CL : 156/205

II FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S.	156/197,205,208,256,257,260,263,264,267,292,322, 156/353,469,470,471; 428/116,118; 83/72

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	US, A, 2,821,616 (SPOTT) 28 JANUARY 1958 See figures 1-2 and 4-7; col. 2, lines 18-35.	1-4
Y	WO, A, WO87/06186 (ASHTON) 22 OCTOBER 1987 See page 2, line 26- page 3, line 12.	1-4
Y	US, A, 3,356,555 (JACKSON) 05 DECEMBER 1967 See figure 2A; col. 1, lines 40-58; col. 3, lines 52-65.	1-4
Y	US, A, 3,741,840 (BOOTH) 26 JUNE 1973 See col. 1, lines 49-61; col. 3, line 54- col. 4, line 4.	1-4
Y	US, A, 4,653,399 (KUEHFUSS) 31 MARCH 1987 See col. 2, lines 51-53.	4
A	GB, A, 312,801 (BONALDA) 15 MAY 1928 See entire document.	1-4
A	GB, A, 740,918 (ROE) 23 NOVEMBER 1955 See entire document.	1-4

* Special categories of cited documents: [10]

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

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

"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

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
19 FEBRUARY 1992	25MAR 1992
International Searching Authority	**Signature of Authorized Officer**
ISA/US	MICHELE K. YODER

Form PCT/ISA/210 (second sheet) (Rev.11-87)