June 27, 1967 H. NOYES 3,328,218

PROCESS OF MAKING A STRUCTURAL ELEMENT

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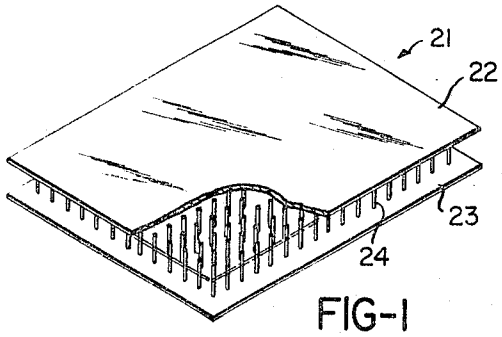


FIG-1

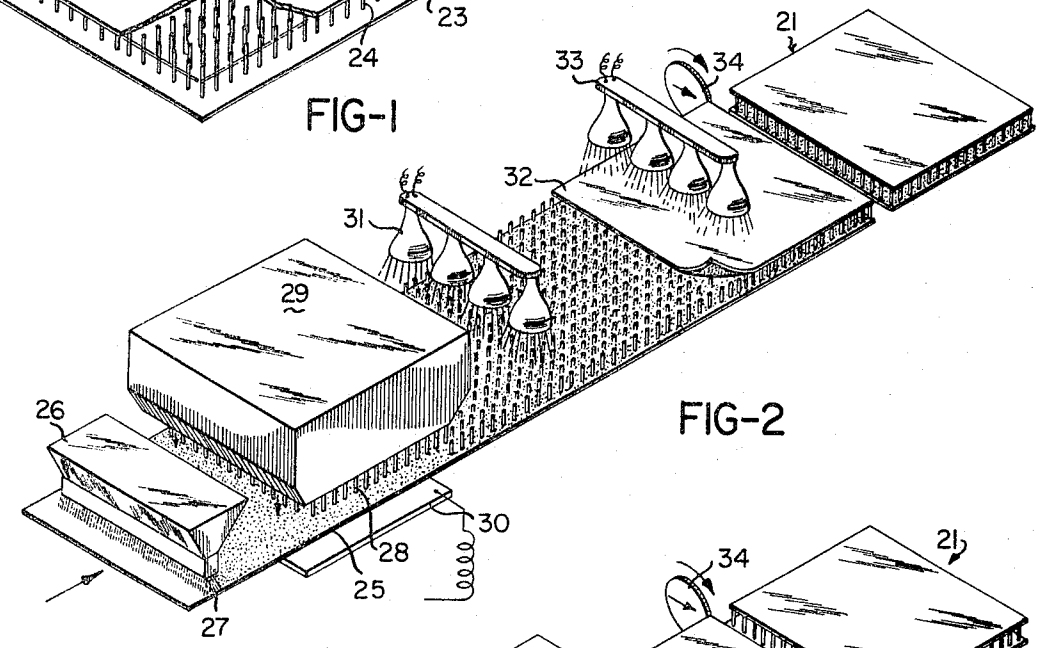


FIG-2

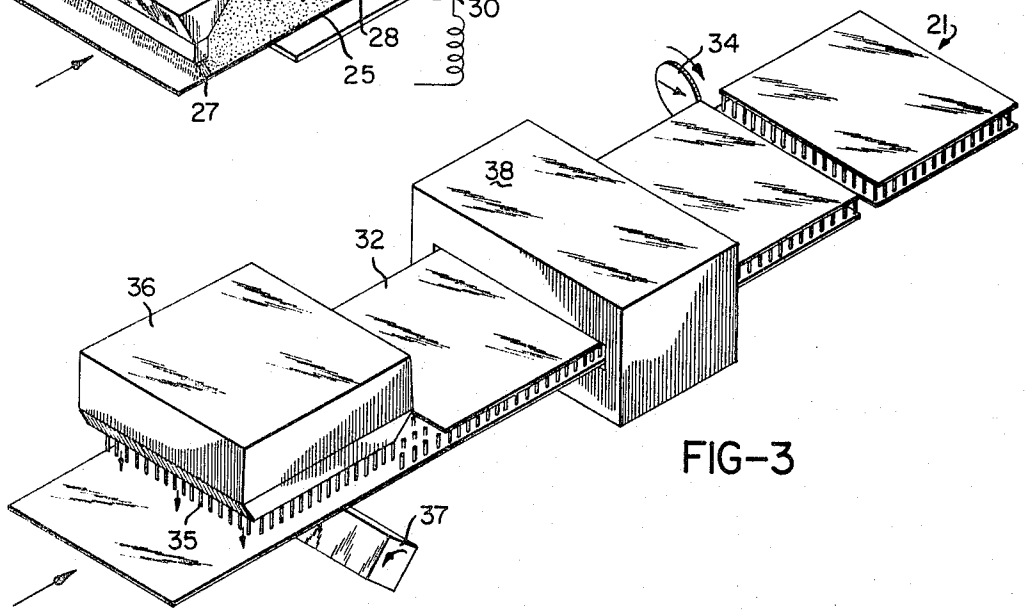


FIG-3

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PROCESS OF MAKING A STRUCTURAL ELEMENT

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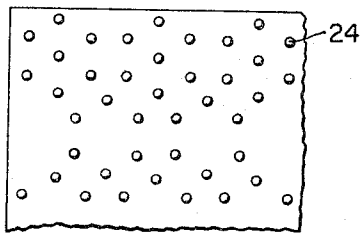


FIG-4

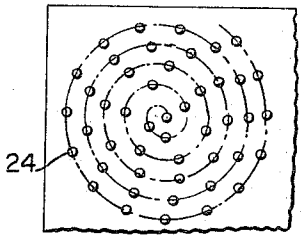


FIG-5

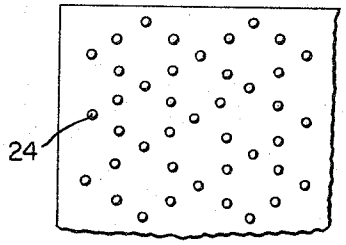


FIG-6

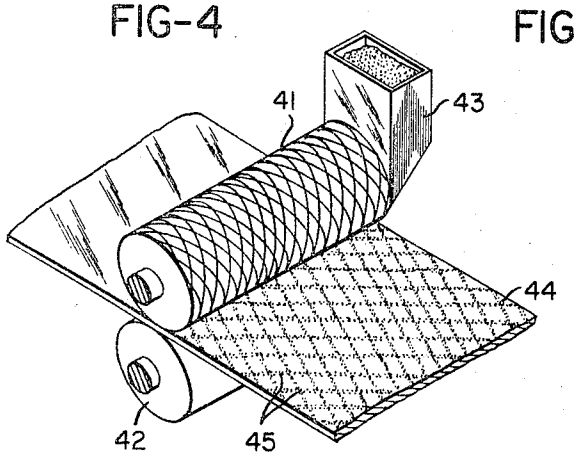


FIG-7



FIG-8



FIG-9



FIG-10

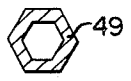


FIG-11

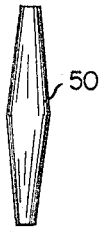


FIG-12

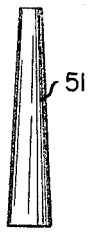


FIG-13

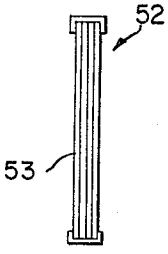


FIG-14

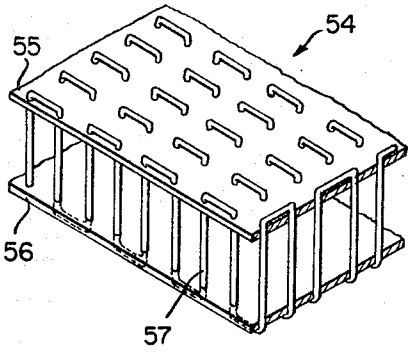


FIG-15

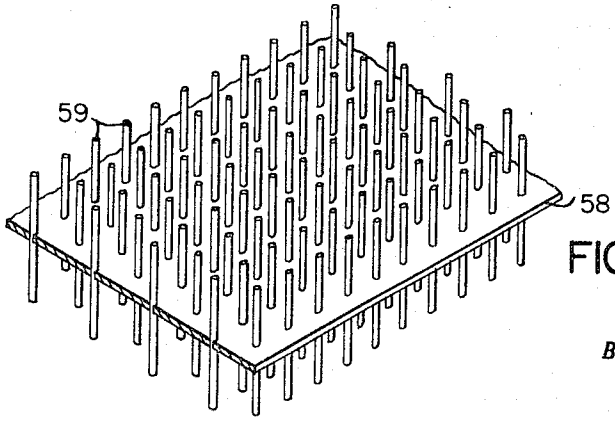


FIG-16

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PROCESS OF MAKING A STRUCTURAL ELEMENT

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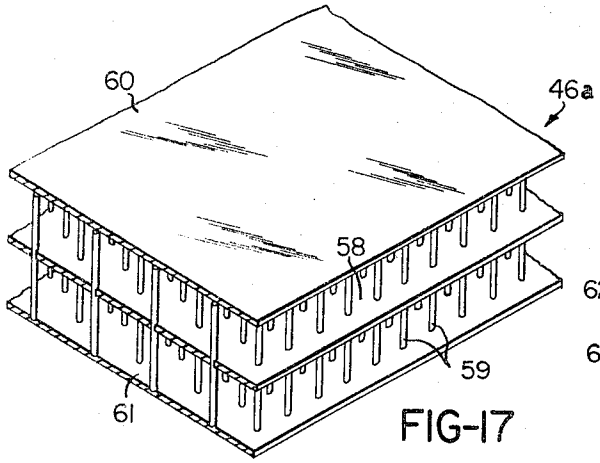


FIG-17

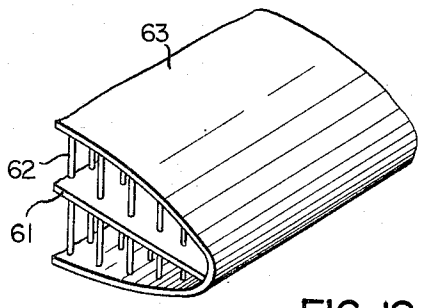


FIG-18

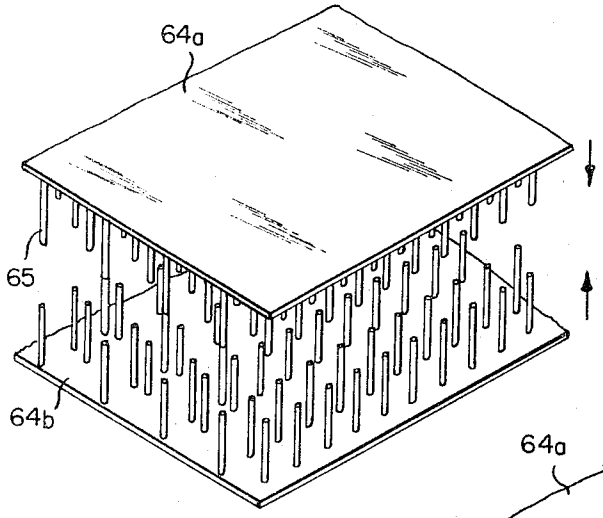
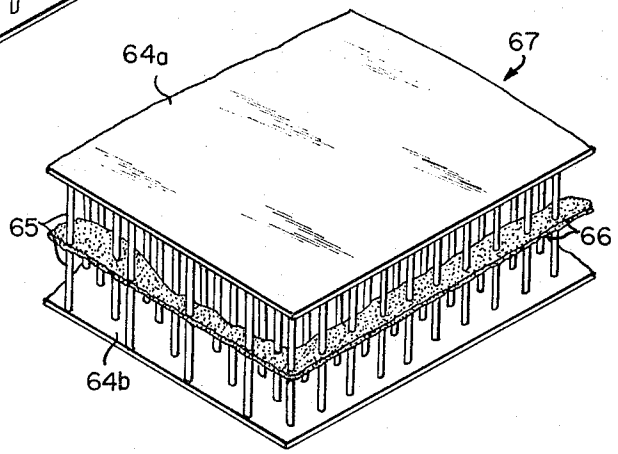


FIG-19

FIG-20



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PROCESS OF MAKING A STRUCTURAL ELEMENT

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FIG-21

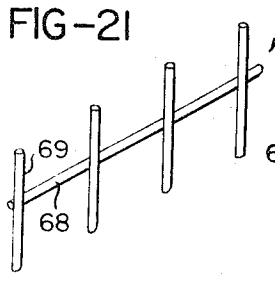


FIG-22

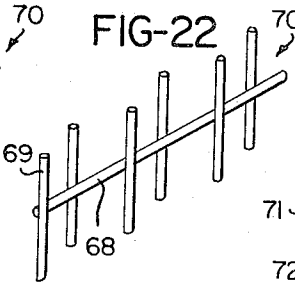


FIG-23

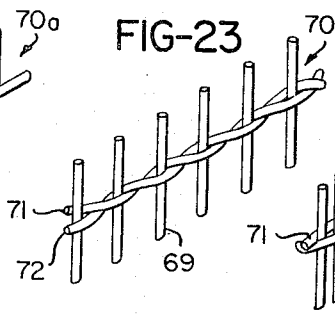


FIG-24

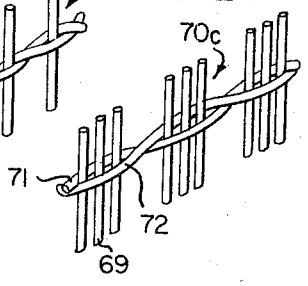
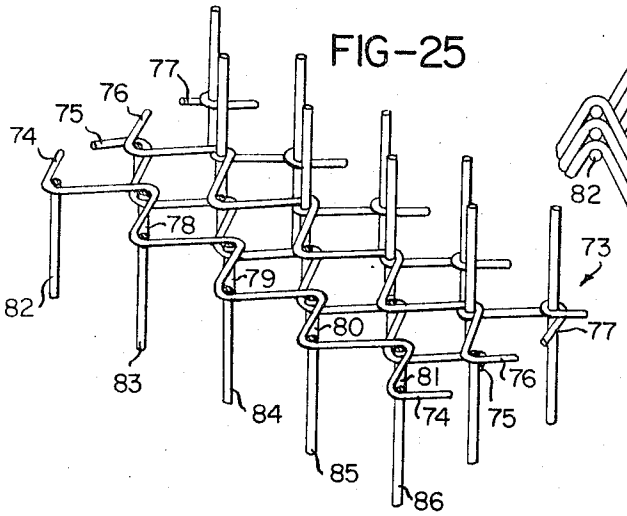


FIG-25



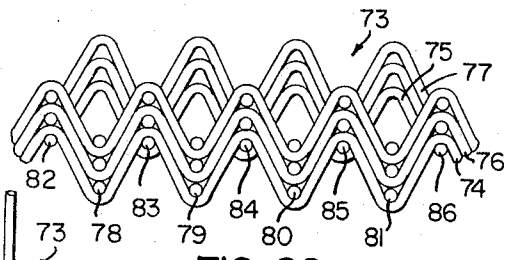


FIG-26

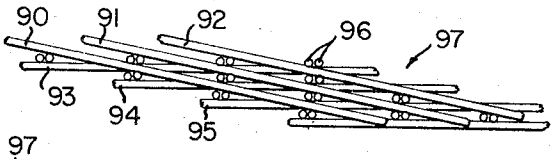


FIG-28

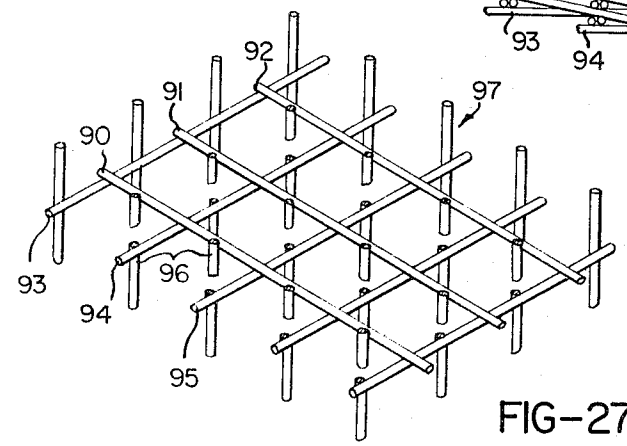


FIG-27

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United States Patent Office 3,328,218 Patented June 27, 1967

3,328,218

PROCESS OF MAKING A STRUCTURAL ELEMENT

Howard Noyes, 111 Folsom Drive, Dayton, Ohio 45405

Filed Apr. 9, 1962, Ser. No. 186,244
2 Claims. (Cl. 156—166)

This invention relates to a structural element, and more particularly to a structural element of the type comprising a plurality of plies which are coextensive but separated and held in spaced relationship by core materials.

Many types of composite structural elements are known in the prior art, some referred to as "structural sandwiches," some referred to as "honeycomb structures," and others bearing similar names. Generally speaking, these elements consist of coextensive parallel outer plies or sheets which sandwich therebetween a core or a filler of a material or combination of materials to provide units which are strong, yet comparatively light. Such a structure most commonly has a core of thin wall plastic, paper or metal sheets placed at right angles to the outer plies in configurations that alternately merge and separate to form openings that look like those of an ordinary honeycomb; hence, the name. Variations of this core structure include rigid polystyrene or urethane foam; sheets of sinusoidal pattern, as in U.S. Patent No. 2,644,777; and a random mass of fiberglass and resin, as in U.S. Patent No. 2,805,-974. These prior art structures have all been designed to produce as tructure having the desirable characteristics of strength, stiffness and lightness.

The present invention contemplates a step forward in this art, providing a composite structure which is greatly superior in strength, stiffness, and lightness. Basically, the invention utilizes slender columnar core members, in which the individual members are oriented at approximately right angles and secured to outer skin members similar to those previously used. As used in this specification, "slender columnar members" refers to rigid small diameter solid or hollow columns ranging from about hairlike filaments to about one-quarter inch in diameter, and having a length at least twice the diameter. The members may be very slender, as in continuous or discontinuous filaments of textile, plastic, or metal, or may be slightly larger in diameter in the form of bristles or tubes. The members may be formed of a single strand of material, or may be of many strands which are spun, intertwined or otherwise grouped; they may be extruded, molded, drawn, or formed by other methods; they may be made of various materials described below; they may be solid or hollow; and they may be cylindrical or have other cross sections, or be of various tapered constructions. There are certain advantages in making hollow cylindrical members by spirally wrapping thin strips of inexpensive material such as paper, to form a unitary member. Such members, and in fact any of the members, may additionally be impregnated or coated with resins or metals. The members may be adhered to the outer plies by methods to be described below, and located in a variety of patterns to be further described. Orientation of the members with respect to the plies is accomplished by many well-known methods. Finally, other variations will produce products having applications; for example, additional plies or other strengthening members may be located between and parallel to the outer plies to improve lateral stability.

The product described herein has wide application in areas requiring structural strength, temperature and sound insulation, and vibration damping. More specifically, it may be used in aircraft and missile structures, building panels, truck bodies, aircraft radar domes, crash helmets, insulating containers, furniture cushioning supports, and supports where vibration damping is required. It has the

further advantage of being capable of forming into many shapes, as will be illustrated below.

It is a principal object of the invention to provide a structural element of superior strength, stiffness, and lightness.

It is a further object to provide such an element having a core of various materials.

It is another object to provide an element that is simple to manufacture.

It is a further object to provide an element capable of circulation of fluid.

These and other objects will be more fully described in the following specification and drawings, in which:

FIGURE 1 illustrates in perspective a preferred form of the invention.

FIGURE 2 is a perspective drawing illustrating one method of forming the product of FIGURE 1.

FIGURE 3 is a drawing similar to FIGURE 2 illustrating an alternative method of producing the product of FIGURE 1.

FIGURES 4, 5 and 6 are plan views of typical elements, with outer ply removed, illustrating modified columnar patterns.

FIGURE 7 is a view illustrating a modified method of depositing adhesive.

FIGURES 8, 9, 10 and 11 are cross-sectional views of typical fibers which may be used.

FIGURES 12, 13 and 14 are views in elevation of modified fiber configurations.

FIGURE 15 is a perspective view illustrating another modified form of the invention.

FIGURE 16 is a perspective view illustrating the core portion of a modified form of the invention.

FIGURE 17 is a perspective view of the invention of FIGURE 16 in complete form.

FIGURE 18 is a perspective view illustrating an additional form of the invention.

FIGURE 19 is a perspective view of another form of the invention, prior to assembly.

FIGURE 20 is a view similar to FIGURE 19, illustrating the completed assembly thereof.

FIGURES 21 to 24 are perspective views of modified components of core sections.

FIGURE 25 is a perspective view of another form of core section using FIGURE 21 components.

FIGURE 26 is a plan view of the core section of FIGURE 25, shown in collapsed position.

FIGURE 27 is a perspective view of an additional form of the invention using FIGURE 19 components.

FIGURE 28 is a plan view of the core section of FIGURE 27 in collapsed position.

Turning now to the drawings, FIGURE 1 illustrates a preferred form of the structure, in which a completed element **21** is composed of coextensive parallel outer plies or sheets **22** and **23**, having members **24** mounted therebetween and oriented at approximately right angles to the plies. The plies may be made of metal, rigid plastics such as styrene or impregnated fiberglass, cardboard, or other materials, depending on the end use of the element. The columnar members may be plastic, such as polystyrene, nylon or polyester; refractory, such as glass, asbestos or ceramic; metal, such as brass, copper, steel, tantalum, molybdenum, tungsten or aluminum; animal, such as hog bristle; vegetable, such as sisal; or other materials according to the end use. The members may be impregnated with resins such as epoxy or polyester, or metals such as solder, or coated with similar or dissimilar materials; for example, plastics may be metal coated or vice versa. In the case of hollow members, the interior and exterior surfaces may be coated. The element **21** may be fabricated by several methods, such as the one illustrated in FIGURE 2. A continuous sheet **25** made

of the material described above is fed along a conveyor system in the direction shown by the arrow. As it passes under the spray head **26**, liquid adhesive is sprayed on the surface; this adhesive may be any of several types, such as phenolic, casein, epoxy, or thermosetting resins, capable of developing high holding strength. While the adhesive is still liquid. a plurality of columnar members such as fibers **28** which are described above, are deposited onto the surface from a flocking apparatus **29**, or similar device. The assembly simultaneously passes over a plate **30** which creates an electrostatic charge, by methods well known in the art, thus orienting the members at approximately right angles to the sheet **25**. The next step in the process involves heating, which may be accomplished by a battery of infrared lamps **31**, or by other well-known means such as hot air or electrical resistance. This sets the adhesive so that the members are firmly placed in this oriented position. Another sheet **32**, upon which a layer of similar adhesive has previously been deposited, is then placed on the exposed ends of the members, with the adhesive surface contacting these ends, or the free ends of the member may be coated. The assembly is then exposed to heat, as by a battery of lamps **33**, to cure the other layer of adhesive. The final step of the operation consists of severing the assembly by means of cutter **34** to provide the finished structural element **21**.

The foregoing is only one example of a method used to provide the desired structure, but many variations are possible. For example, the assembly can take place on pre-cut plies instead of continuous sheets. In lieu of liquid adhesive, a solid activatable adhesive sheet or solvents which react with a plastic surface may be used. The adhesive need not be sprayed, but may be brushed or rolled on the surfaces. In lieu of electrostatic orientation, magnetic attraction (in the case of metal or metal-dipped fibers) may be used; the fibers may be inserted into preformed holes; or even stitched in place. A useful corollary of the employment of resins has been found, in that these resins will tend to flow partially along the surfaces of the columnar members, or between adjacent members, by capillary action. This provides added stiffening.

Another variation of the above method is illustrated in FIGURE 3, in which the members **35** are blown or flocked from reservoir **36** onto a metal sheet **25**. By use of vibrating mechanism **37** contacting the sheet, these members become oriented at approximately right angles to the sheet. The upper sheet **32** is then placed on the exposed end of the members and the entire assembly is passed through a brazing or welding furnace **38** to bond the entire assembly into a complete unit, if the members are metal, or a lower temperature oven, if heat-responsive adhesives are used. The completed sheets are severed to length, as before, to form a completed element.

The member illustrated in FIGURE 1 utilizes a regular pattern of distribution of the columnar members, and it is understood that the length of the spacing thereof may be varied according to the desired strength of the member. This spacing, and hence the density, is in ratio to the strength. Also, it is clear that the length of the members with reference to the diameter (known as the slenderness ratio) is in inverse ratio to the strength of the member. As an alternative to the pattern shown in FIGURE 1, the members **24** may be arranged in groups of seven (as in FIGURE 4) or groups of three, four, five, six, or any other number; or they may be arranged in geometric patterns such as concentric circles, spirals (as in FIGURE 5), or honeycomb. They may also be arranged in rows, such as in FIGURE 6, in which a diamond pattern is formed thereby. These patterns may be obtained by preforming the holes and inserting the members as previously mentioned, or by preapplying adhesive in specific patterns. An example of this latter method appears in FIGURE 7, in which the adhesive is applied through a roller **41** having perforations in a diamond pattern. By

passing sheet **44** between this roller **41** and a lower roller **42**, adhesive is fed from a reservoir **43** into the roller **41** and creates the adhesive lines **45** as shown. Then when the sheet is exposed to the process shown in FIGURE 2, adherence of members to the adhesive along the prearranged lines will take place.

The cross section of the members may also be varied from round as member **46** in FIGURE 8, and hexagonal as member **47** in FIGURE 9, to such shapes as square, triangular, star-shaped, etc. They may also be hollow, as members **48** and **49** in FIGURES 10 and 11. These sections are particularly susceptible of formation by extrusion or drawing techniques. The members may also vary in configuration; in addition to conventional cylindrical forms, as shown in FIGURES 1 to 3, a member **50** may be double-tapered as in FIGURE 12 or single-tapered as member **51** in FIGURE 13. Members **53** may be assembled and the ends dipped in adhesive as in FIGURE 14 to provide a group **52**. These configurations provide additional strength characteristics.

FIGURE 15 illustrates a modified form of the invention in which a structural element **54** is formed of plies **55** and **56** similar to plies **22** and **23**, and has core members which are oriented by a different means. This is accomplished by interlacing or intertwining a continuous filament **57** between plies as shown, thus creating a plurality of members which provide the core. As a variation of this principle, other interlaced arrangements may be employed to create various patterns and forms. This type of element may also be shipped inexpensively by treating the filaments with resin, but not curing them and keeping them soft. The entire element may be collapsed flat until received; at that point it may be treated by chemicals or heat to react with the resins, thus stiffening the members while the plies are returned to their previous relationship.

The foregoing constitutes a description of various forms of the invention in which merely an inner and an outer ply are used in conjunction with the core material. It is, of course, understood that any desired number of the complete elements may be stacked upon each other to form a thicker element, and the adjacent plies cemented or otherwise adhered.

It is also contemplated that the structural element may be made in a manner that will provide lateral stability to the fibers during the fabrication thereof. For example, an additional lateral paper ply, parallel to outer plies may be inserted while fabricating; then burned off during subsequent heating operations. This enables the columnar members to be positioned for special shaping as an airfoil shape shown in FIGURE 18. Similarly, ice, foamed plastics, or wax might be employed to create this lateral stability during fabrication; in the case of ice or wax, heat is used to remove them as in the "lost wax" method; in the case of foam the structure is disintegrated or it is dried out during the heating processes.

Lateral stability may also be desired on a permanent basis, in which an additional ply is made a part of the structure as finally used. Such structures are illustrated in FIGURES 16 to 20, and are used when the slenderness ratio is so high that the bending loads are greater than compression loads. The use of the lateral stiffener will effectively reduce the slenderness ratio and overcome any serious tendency to bend. The additional ply may be of the same material as that of the outer plies, or it may be of a different material. The use of inexpensive materials, such as paper, cardboard, or metal foil is practical, since in many cases materials of high structural strength are unnecessary for this purpose.

Turning now to FIGURE 16, one method of utilizing a lateral stiffener is illustrated, in which a sheet **58** has members **59** inserted therein so that the sheet is located midway of these fibers. The sheet may be pre-drilled or punched, or the fibers may be inserted as by a tufting machine. Again it is understood that the fibers may be

arranged in various patterns as previously discussed. This entire assembly is bonded to outer plies **60** and **61** to form the completed member **46***a* shown in FIGURE 17, using one of the previously described methods.

FIGURE 18 illustrates a variation of the members of FIGURE 17, in which the outer ply **63** is a continuous member having a curvature such as found in an airfoil section. The central stiffener **61** has members **62** mounted as in FIGURE 16, except that the members are of different lengths to conform to the shape desired. This may be accomplished by forming the members of desired length, or by a machining operation which creates a curved plane on the members' surfaces. The same result may also be obtained by imbedding the members in foam, wax, etc., as previously described, in order to facilitate the machining operation. Another unexpected result from this type of construction arises from the fact that the members do not create a closed core, as in a conventional honeycomb structure; it is now possible to circulate refrigerating fluids within the elements for cooling purposes; or heating fluids within the elements for heating purposes. Circulation of cooling fluids have particular utility in airfoil sections where high speeds generate frictional heat that must be dissipated, as well as in walls or floors where cooling is desired for human comfort. The heated elements have particular utility in manufacturing floors or walls of buildings, thus providing an inexpensive means for providing radiant heat, and may also be used in airfoil sections for anti-icing or de-icing. It is understood that elements used for cooling or heating are properly sealed to provide a closed unit for continuous circulation. It should be noted that such a section may also be formed with a lateral member, as in the showing of FIGURE 18, or without the lateral member, as in FIGURE 1.

FIGURES 19 and 20 illustrate another form of the invention in which a lateral stiffener of a different type is employed. In accordance with this modification, a unit consisting of ply **64***a* and columnar members **65** is assembled by one of the methods described above, and a second unit of ply **64***b* and members **65** is also assembled. These units are shown in FIGURE 19, and as indicated by the directional arrows, they are assembled with the free ends of its members in contact. Between these ends is applied an adhesive layer **66**, which may be in liquid or solid form and of any of the compositions previously referred to. This layer when setting provides the lateral stiffener to perform the same function as those above described. If desired, the ends of the members may be pre-dipped to form the stiffener. It should be noted that the members are sufficiently close to create a more or less continuous adhesive or resinous ply, although the closeness of these members may not be truly illustrated in the drawings.

FIGURES 21 to 24 illustrate a unique form of the invention in which the core is formed of components consisting of longitudinal strands to which are fastened columnar members (of the type previously described) located at intervals and at approximately right angles to the strand. The component is formed into units of indefinite length which may be coiled or otherwise stored until formed into the completed cores as presently described. The component **70** of FIGURE 21 is formed of strand **68** to which are secured, at approximately right angles, the members **69** at appropriate intervals. These members may be secured by adhesives, heat sealing (in the case of plastics), or brazing or welding (in the case of metals). The strand may be of any convenient material as described with reference to the members. FIGURE 22 illustrates a variation in which component **70***a* is formed of strand **68** as before, but members **69** are located at opposite sides of the strand. FIGURE 23 illustrates a component **70***b* in which strands **71** and **72** are intertwined and lock in the members **69**. As a further variation, FIGURE 24 illustrates a component **70***c* in which the strands **71** and **72** intertwine and hold these members **69** within each loop. In all cases, the members may be adhered as stated above.

FIGURE 25 illustrates a completed core **73** formed of a number of the components of FIGURE 21 which are interlocked as shown. It is noted in FIGURE 21 that the strands are located slightly off center with respect to the fibers; this permits the strand of one component to be wrapped around a fiber of an adjacent component, as shown in FIGURE 25, in which these separate components form a diamond pattern. For example, the strand **74** is wrapped around members **78, 79, 80** and **81** which are attached to strand **75**; the members **82, 83, 84, 85** and **86** being attached to strand **74**. Similarly, the strands **76** and **77** are intertwined around the members which are attached to the adjacent strands. By means such as this, any desired pattern of core may be provided. Further, adhesives, heat sealing (as in plastics) or brazing (as in metals) are means which may be used as supplements to, or in lieu of, the interlocking which is shown. It should be noted that the strands of the components provide lateral stiffeners as do the stiffeners of FIGURES 16 to 20, and the core sections may be interchangeably used. The core shown is merely illustrative of the invention but may be made of indefinitely large size.

FIGURE 26 illustrates one of the advantages of the core illustrated in FIGURE 25. After assembly, the core **73** may be collapsed as shown, by laterally shifting the strands about the members which act as pivots, causing the looped portions of the strands to nest into each other. This considerably lessens shipping costs, since it is possible to ship the collapsed core and later reconstruct it in the FIGURE 25 shape before assembly to outer plies as in FIGURES 17 or 18.

FIGURE 27 illustrates another form of core, designated by reference numeral **97**, which may be made by assembling a plurality of core components **70** of FIGURE 21. According to this modification, a series of strands **90, 91** and **92**, to which columnar members **96** are attached (as in FIGURE 21) are placed in parallel relationship. At right angles thereto are placed another series of strands **93, 94** and **95** which lie below the other strands. The assembly is now interlocked in the manner of an egg crate, with the offset relationship previously mentioned creating this arrangement. The strands may be adhered to adjacent ones by the previously mentioned adhesive, heat, or other methods. This structure, which may be extended indefinitely to form any desired size, is now a completed one and may be used between plies interchangeably with other cores.

FIGURE 28 illustrates the core of FIGURE 27 in collapsed position, as for shipping. This is accomplished by merely shifting the strands (again, as in an egg crate) to provide the flat configuration shown. When this is received it need only be returned to the FIGURE 27 form and used between plies as above.

The products and methods described above are by no means the only ones embodying the inventive concept which involves the use of slender columnar members, oriented at approximately right angles to the outer plies, as cores for sandwich type structural elements. When very slender members, such as fibers, are used, they provide the unusual phenomenon of fibers in compression instead of tension or bending such as normally occurs.

The examples described herein are merely illustrative of the invention and are in no way limiting. Other embodiments are contemplated within the scope of the invention. It should also be noted that the drawings may not truly represent the dimensional relationships, but are shown for clarity.

I claim:

1. The method of manufacturing a structural element having compressive strength from a pair of outer plies and an intermediate ply, comprising the steps of forming rigid filaments having a length at least twice the diameter, inserting said filaments through said intermediate

ply and fastening at approximately right angles thereto, and fastening said outer plies to the free ends of said filaments to form a unitary element.

2. The method of manufacturing a structural element having compressive strength comprising outer plies and a core section therebetween, comprising the steps of fastening rigid filaments to a strand at spaced intervals, securing a plurality of such strands together to form a completed core section, and fastening the ends of said filaments to said plies to secure said core section thereto.

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