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B5N
B5A
Selected US specifications from IPC sub-class B32B

(54) Honeycomb materials

(57) A method of making a high temperature polymer honeycomb structure is described in which layers of the polymer 12 are placed in a tool 10, 16 with interposed shaped formers 14, heat and pressure sufficient to cause the polymer in different layers to coalesce is appplied and the tool cooled. The polymer may be polysulphone, polyethersulphone, polyetherketone, polyetheretherketone, polyetherimide, polyphenelene sulphide, or a polyamide; and may be used in pure form or be reinforced with glass, carbon, quartz, boron or other reinforcing fibres. The polymer layers may be un-formed and heated to a temperature at which they are moulded; or the layers may be pre-formed, laid up in the tool with touching surfaces coated with a solution of the polymer material and heated to a temperature at which the touching surfaces fuse. The cell walls of the honeycomb may be metallised and one or more skins of the same or a different polymer fixed to thereto by painting a surface of the or each skin with a solution of the polymer therein and bringing the painted surface of the skin into contact with the honeycomb with application of heat and pressure.

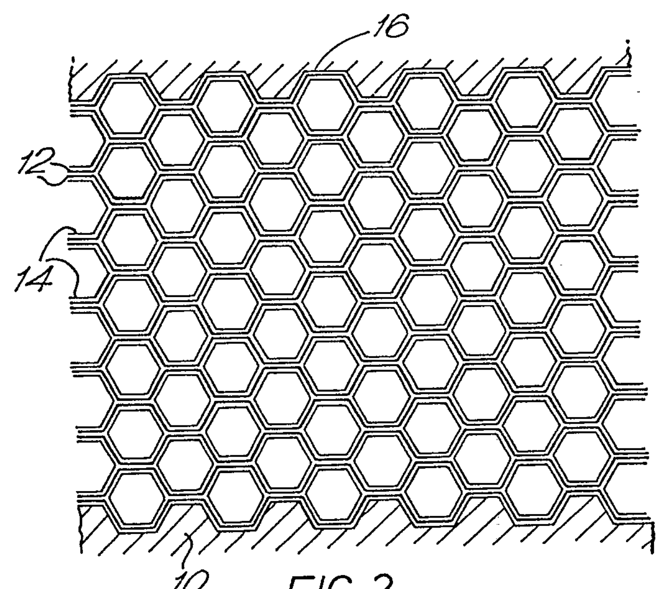

FIG. 2.

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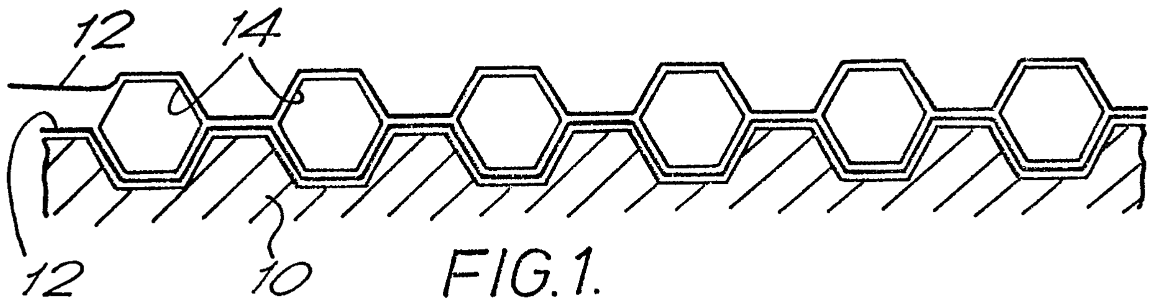


FIG.1.

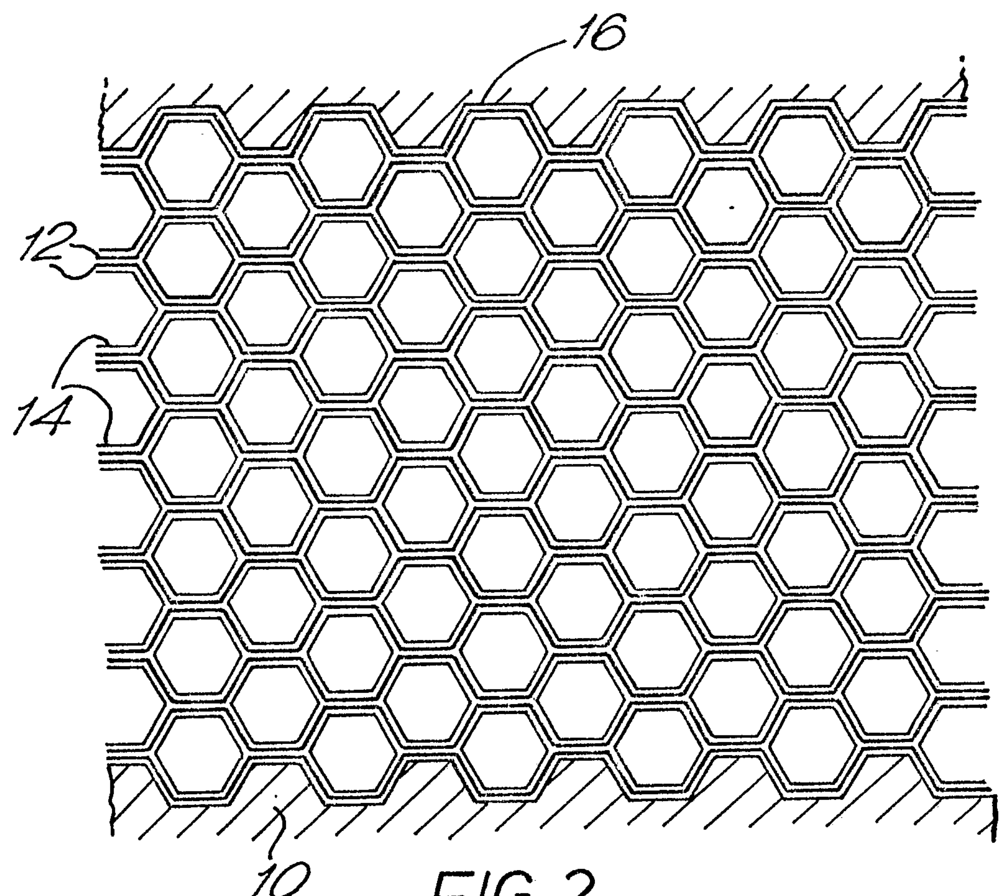


FIG.2.

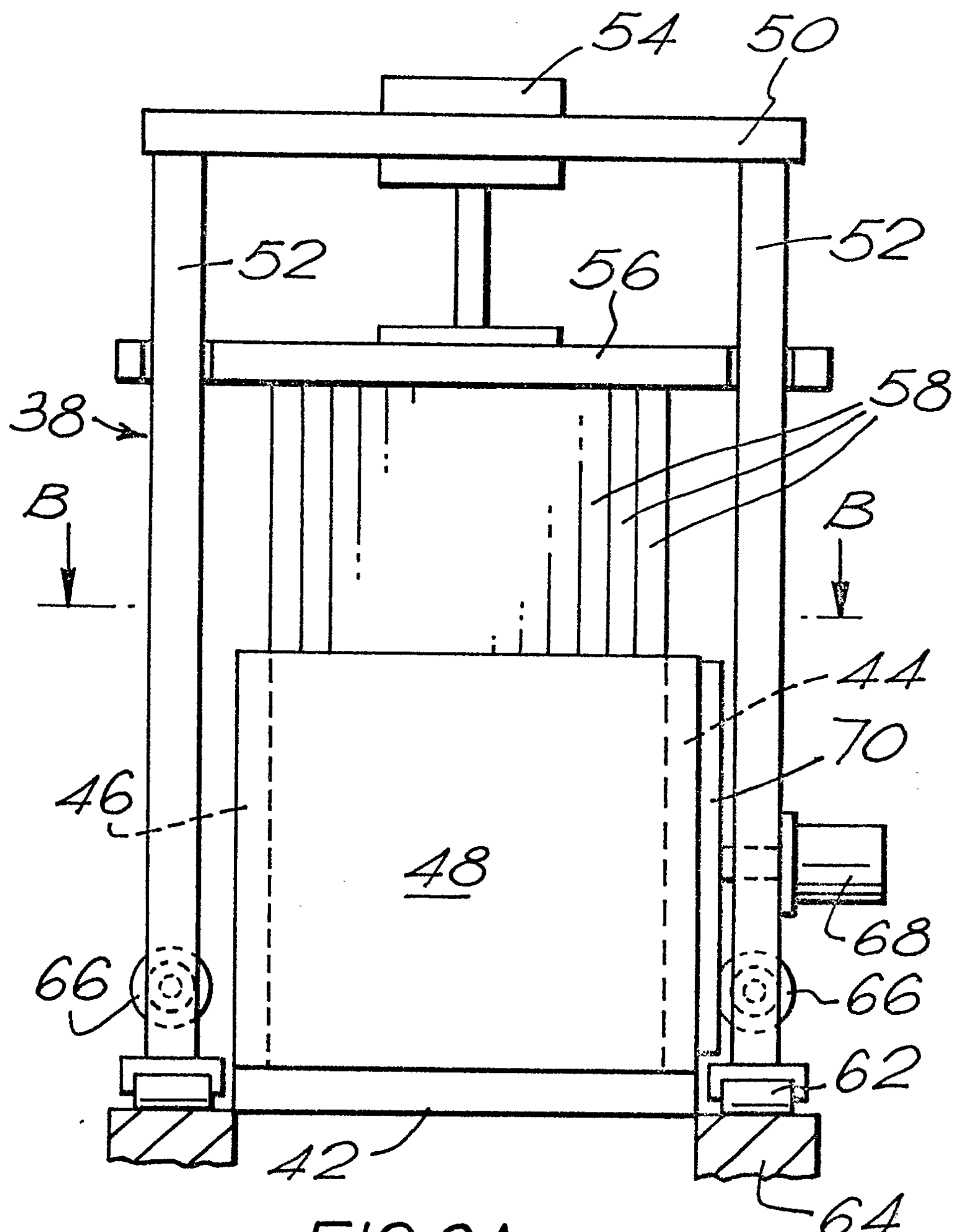
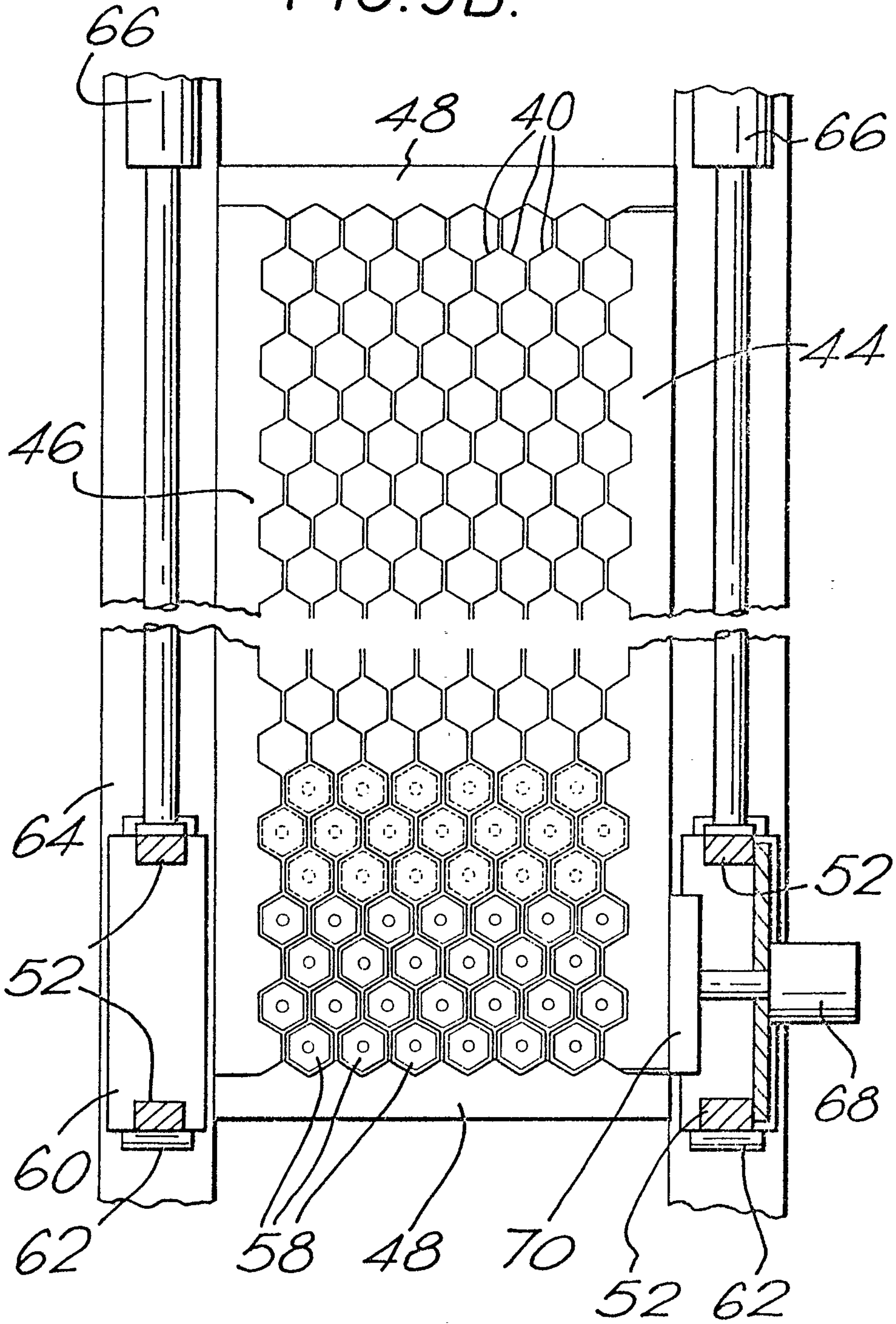


FIG.3A.

FIG. 3B.



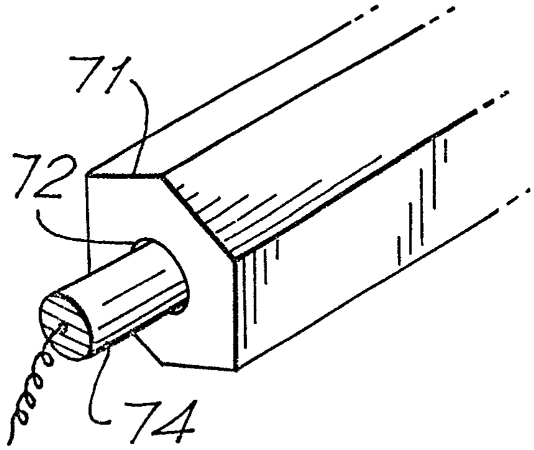


FIG. 3C.

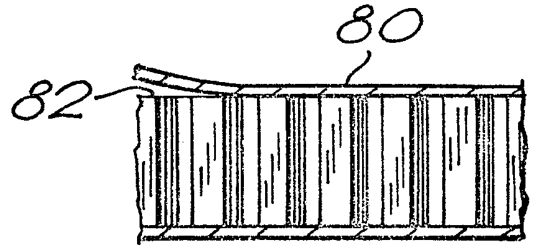


FIG. 4.

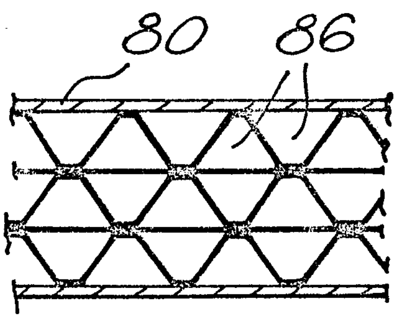
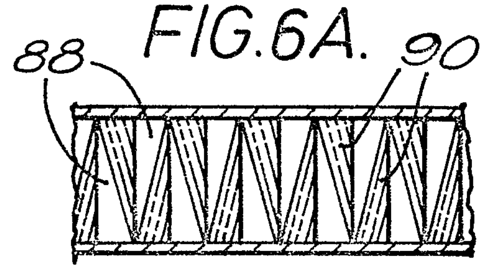


FIG. 5.

FIG. 6A.



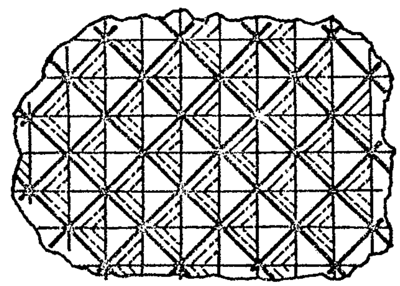
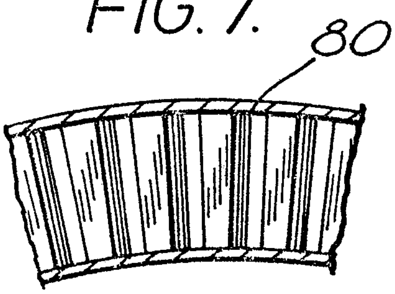


FIG. 6B.

FIG. 7.



SPECIFICATION

Lightweight high temperature thermoplastics material structures

The invention concerns the manufacture of lightweight high temperature thermoplastics material structures, in particular honeycomb structures.

The manufacture of lightweight structures from polymer materials is known. To date low temperature foamed thermosetting and thermoplastics material structures have been produced by the polymer being foamed in a mould of the desired shape. The disadvantages of using foamed polymer materials, particularly low temperature polymer materials, to form any structure include the low strength and friability of the finished material (particularly with low temperature polymer materials) and the difficulty of achieving a consistent density from place to place throughout the finished article.

The production of regular cellular structures of unfoamed polymer material - hereinafter referred to as honeycomb structures - has also been proposed and these structures are preferred when it is desired that the strength/weight ratio be higher than can be obtained with foamed structures.

When using the known technique for forming honeycomb structures difficulties arise in varying the shape of the 'cell', ensuring the interstices of the cells are fully loaded with the polymer material and ensuring the cell walls do not collapse as the structure is made. Above all the known technique for making honeycomb structures in thermoplastics materials is limited to polymer materials capable of extrusion and cannot readily be used with high temperature thermoplastics materials or with fibre reinforced polymer materials.

To increase the strength of the known lightweight polymer structures it is known to provide foamed or honeycomb polymer cores (made by the above methods) lying between and bonded to metal or composite (e.g. fibre reinforced polymer) skins. To date low temperature foamed and honeycomb polymer material cores have been bonded to skins with adhesives provided as a separate layer adversely adversely affecting the characteristics of the article.

More recently techniques for foaming high temperature aromatic thermoplastics materials (such as polyethersulphone) have been proposed - see for example U K Patent 2 083 045 - and welding techniques devised enabling such foamed materials to be bonded to skins to form composite, sandwich structures with considerably improved strength/weight ratios. However, no useful techniques for forming honeycomb structures from high temperature thermoplastics are known to us at present.

Objects of the invention include the provision of methods of making lightweight honeycomb structures from high temperature thermoplastics materials, which may be fibre reinforced, and also the subsequent attachment of a core formed in such a way to a pre-formed skin or skins to provide an integrated composite, sandwich structure without use of adhesive.

According to one aspect the invention provides a method of making a high temperature polymer honeycomb structure comprising the steps of positioning in a tool layers of the high temperature polymer material with interposed shaped formers, applying heat and applying pressure to the tool sufficient to cause the polymer material in different layers to coalesce, cooling the polymer and removing the resultant honeycomb structure so formed. The high temperature polymer material may be one of polysulphone, polyethersulphone, polyetherketone, polyetheretherketone, polyetherimide, polyphenelene sulphide, a polyamide or the like; and may be used in pure form or be reinforced with glass, carbon, quartz, boron or other fibres reinforcing fibres.

The layers of thermoplastics material may be unformed heat being applied to them to raise their temperature to a level at which the thermoplastics material is moulded to form the honeycomb structure. Alternatively, the layers of thermoplastics material may be pre-formed and laid up in the tool with touching surfaces thereof coated with a solution of the polymer material heat being applied to raise the temperature of the touching surfaces of the layers to a level at which those touching surfaces fuse to form the honeycomb structure.

The formers may be hollow tubes and heating be effected in an oven, or at least some of the formers may be electrical heating elements by which heat is applied to the polymer material. Air may be passed through the said tubes to aid the heating and cooling of the polymer material.

The tool may be used to apply heat and pressure sequentially to adjacent sections of the laid up polymer layers therein, enabling the honeycomb structure to be made continuously, lengths of the polymer layers being passed sequentially to the tool in which they are laid up and formed into sections of honeycomb structure.

The walls of the cells of the honeycomb structure may be metallised after formation, and one or more layers of high temperature polymer material (which can be of the same or a different polymer) may be affixed to the honeycomb structure by painting a surface of the or each layer with a solution of the polymer material therein, the painted surface of said layer thereafter being brought into contact with the honeycomb structure with application of heat and pressure.

Other aspects of the invention provide a lightweight high temperature thermoplastics material honeycomb structure made in accordance with the methods noted above and apparatus for putting the methods noted above into effect.

The above and other aspects features and advantages of the invention will become apparent from the following description of embodiments of the invention made with reference to the accompanying drawings and in which:-

Figures 1 and *2*, illustrate a first method embodying the invention,

Figure 3, illustrates apparatus for use in a second method embodying the invention, and

Figures 4 to *7*, show various sample structures made by the methods illustrated in Figures 1 to 3.

Figure 1, shows an arrangement including a base plate 10 configured to enable generation of a desired (hexagonal) cell shape in a honeycomb structure to be made. Upon plate 10 is laid a flexible layer 12 of high temperature thermoplastics polymer impregnated fibres reinforced material.

The reinforcement in layer 12 may be of any suitable material e.g. fibres of glass, boron quartz, or carbon, compatable with the polymer used. The fibres in layer 12 may be of any suitable form, e.g. they may be woven, knitted, laid-up, aligned continuous fibres or a mat of chopped fibres. Layer 12 is preferably pre-impregnated with an aqueous suspension of finely divided particles of an aromatic, high temperature polymer such as polysulphone, polyethersulphone, polyetherketone polyetheretherketone, polyetherimide, polyphenelene sulphide, a polyamide or the like; such as is described in our copending International Patent Application PCT/GB85/00558.

As shown a plurality of hollow hexagonal stainless steel tubes 14 which conform to the desired cell cross-section is placed on layer 12 and then a further layer 12 of the polymer impregnated reinforcing fibres is placed on top of the tubes 14. This stacking process alternating layers 12 of high temperature thermoplastics polymer impregnated fibres reinforced material and tubes 14, is continued until the desired 'stack height' has been reached and then, as shown in Figure 2, a second plate 16 configured to the desired shape is placed on top of the stack.

The complete stack, held between the plates 10 and 16 is now placed in an oven (not shown) and heated to above the temperature at which the polymer material melts (e.g. for polyethersulphone above approximately 325°C). Pressure is applied to the stack (between the plates 16 and 10) to consolidate the molten thermoplastics polymer material and the stack is allowed to cool to a temperature below the glass transition temperature of the polymer used, desirably to ambient room temperature. Air may be passed through the hollow tubes to assist both the heating and the cooling of the stack.

After the stack has cooled the pressure on it is released and the tubes 14 withdrawn leaving a high temperature thermoplastics polymer impregnated fibres reinforced material honeycomb structure.

The fibres reinforced material polymer layers 12 may be as described or have added thereto decorative or functional fillers if desired. Pure polymer in the form of film or powder may be added to the layers 12 to increase the polymer/fibre ratio if desired. In one alternative arrangement the fibre reinforcement need not be pre-impregnated with the polymer but the polymer may simply be applied, in fine powder form, as the layers 12 are laid up. Instead of polymer impregnated fibres reinforcement pure polymer in the form of sheets, filsm or in fine powder form may be used to form the honeycomb if desired.

The particular method described with reference to Figures 1 and 2 permits the close control of the sizes of the cells and both the size and polymer loading in the interstices between the cells, and of the overall consistency of the finished product. In this way it is possible to manufacture a product having mechanical characteristics (e.g. stiffness) similar to those of the basic polymer impregnated fibres reinforced material, but which is, however, very considerably lighter than a similar sized structure made from 'solid' polymer impregnated fibres reinforced material.

The method described with reference to Figures 1 and 2 may be modified by bringing the polymer material to the temperature at which it melts by using electrical heater elements to replace all or some of the hexagonal tubes 14 and not placing the assembled tool in an oven.

Another method of making honeycomb structures from high temperature thermoplastics polymer impregnated fibres reinforced materials embodying the invention is illustrated highly schemmatically in Figure 3; which shows at A a side view of apparatus for putting the method into effect, at B a plan view drawn on line B-B of Figure 3A, and at C a perspective detail view of part of the apparatus.

In accordance with this second method lengths 40 of pre-formed high temperature thermoplastics polymer impregnated fibres reinforced material are laid on edge on the base 42 of a tool 38 between a floating side plate 44 and a fixed side plate 46. The tool has fixed end plates 48 as shown.

The lengths 40 are pre-formed to have the corrugated cross section shown (for example; by pre-forming layers impregnated with a polymer dispersed in water such as as those noted above, or pre-forming layers impregnated with a solution of the polymer in the manner disclosed in our U K Patent 2 113 140B) and are laid up in the tool 'back to back' such that the crests of the corrugations of adjacent layers are in contact to form hexagonal cells. Prior to their being laid up in the tool the faces of each layer which will contact adjacent layers are coated with a solution of the polymer matrix material of the lengths.

The fibres reinforcement in the lengths 40 may, once again, be of any suitable material e.g. glass, boron, quartz or carbon, compatable with the polymer used and of any suitable form, e.g. woven, knitted, laid-up, aligned continuous fibres or a mat of chopped fibres. The lengths may be formed in the continuous moulding process in the above noted U K Patent or in any other suitable way, the lengths may be formed in the piece if desired. As in the process described above with reference to Figure 1 and 2, the faces of the plates 46 and 48 against which the outermost lengths 40 bear are shaped to fit the corrugations therein.

Tool 38 has a cross bar 50, supported on pillars 52 at either side of the tool, and in turn carries a pneumatic pump 54 operable to move a beam 56 slidably mounted on the pillars below the cross bar 50, towards or away from the base plate 42. Beam 56 has loosely coupled thereto and depending therefrom, four rows of electrical heater elements 58 shaped to conform to the shape of the gaps between the lengths 40 and which, in use, can be positioned so that, when brought into register with ones of the gaps they can be driven into these gaps by operation of the pump 54.

The pillars 52 are supported on assemblies 60 at either side of the tool which have wheels 62 resting on tracks 64 and which are drivable by pneumatic means 66 to move along those tracks to carry pillars 52, cross bar 50, beam 56 and therefore the elements 58 along the length of the tool.

The assembly 60 on the side 44 of the tool incorporates a pneumatic ram 68 - lying in the plane of the elements 58 - the operative end of which comprises a plate 70 which may be brought to bear on the floating side plate 44 of the tool. Plate 70 is the depth of the tool and has a width approximately equal to the width of the four suspended rows of elements 58, that is to say the width of the four rows of hexagonal cells formed by the laid up lengths 40 in the tool into which those elements may be inserted.

After the lengths 40 have been coated with the matrix material solution and laid up in the tool as shown, and the heaters have reached their operating temperature (for polyethersulphone approximately 200°C) the means 66 are operated to carry the assemblies 60 and beam 56 to a first position in which the pump 54 may be operated to drive the heater elements 58 into the four rows of cells formed between adjacent lengths 40 at the extreme end of the tool as shown in full line in Figure 3B. The ram 68 which has been carried to the same position by movement of the assemblies 60 is operated to apply pressure to the floating side wall 44 in the region of the lengths 40 having the heater elements 58 therebetween.

After sufficient time has elapsed for the heaters to cause local melting of the touching, polymer solution solvent coated - and therefore reduced glass transition temperature areas of the lengths 40 (and to volatize any remaining solvent), the ram 68 is operated to apply a pressure of approximately 200 psi to the plate 70 bearing on wall 44 for a period of time, 10 to 30 seconds, sufficient to cause the polymer matrix material in adjacent lengths 40 to fuse or coalasce. Then the pressure applied by ram 68 is released and pump 54 reverse operated to withdraw the elements 58 from the gaps (now cells) in which they were located.

Thereafter the means 66 is operated to drive the assemblies 60 along the length of the tool to bring the heater elements 58 into alignment with the next four rows of gaps into which they are driven (shown dotted in Figure 3B) by operation of the pump 54, and the ram 68 again operated to cause a further section of the structure to be formed.

The same process is repeated in steps along the length of the tool until each area of the stack of lengths has been consolidated in the same way.

As noted the tool illustrated in Figure 3 is shown highly schemmatically and it will be appreciated it includes means (not shown) for monitoring and controlling the temperature of the elements 58 to ensure that heating is effected to bring the local temperature of the abutting surfaces of the lengths 40 above the locally reduced glass transition temperature but that the temperature of the polymer matrix as a whole does not rise above the temperature at which it melts. Further control means are provided to precisely control the length of each step movement of the assemblies 60.

It will further be appreciated that the particular arrangements described for the various assemblies may be altered without departing from the scope of the invention: for example the wheel/track arrangement (62/64) may be replaced by a toothed wheel/rack or a simple slider/rail arrangement; the pneumatic pumps and ram (54/66/68) may be replaced with any other hydraulic/mechanical/electrical arrangement.

In an alternative arrangement the end walls 48 of the tool are removed and the means 60 for moving the assemblies 60 replaced by means for moving the base 42 of the tool upon which the laid up lengths are supported such that they move through the tool in precisely defined steps allowing indefinite lengths of honeycomb structures to be made.

The heating elements 58 are preferably of the form shown in Figure 3C, namely having an outer stainless steel member 71 of the desired shape with a central, circular, blind bore 72 into which is fitted an electrical heating element 74. Such an arrangement enables different cell shapes to be readily obtained simply by alteration of outer shape of the member 71.

It will, of course be appreciated that the particular form of heating element shown in Figure 3C may be varied, and further that the same or a different form of heating element may be used in the arrangements described above with reference to Figures 1 and 2.

As soon as the honeycomb high temperature thermoplastics polymer impregnated fibres reinforced material structures have been made - in accordance with any of the alternative methods described above - it is possible (if desired) for them to be cut, e.g. with a slitter saw, to any particular required shape.

The honeycomb structures so made may be used on their own or they may be provided with skins in the following way. Pre-formed skins 80 (see Figure 4) of preferably the same (but possibly a different) high temperature thermoplastics polymer impregnated fibres reinforced are coated on one side with a solution of the polymer to reduce the glass transition temperature of the matrix material. The extreme ends 82 of the cells of the honeycomb structure may also be painted with the same solution. The painted side of the skin 80 is then brought into contact with the extreme ends 82 of the honeycomb cells and light pressure applied - sufficient to ensure the skin fully contacts the structure - by pressure plates (not shown) and the assembly is heated either totally (in an oven) or locally (using heated pressure plates) to a temperature above the locally reduced glass transition temperature - but below the melt temperature of the main body of the matrix material. In this way the the skins 80 are welded onto the high temperature thermoplastics polymer impregnated fibres reinforced honeycomb structures which have been made and at the same time the solvents used in the polymer solution are volatized - restoring the matrix material to its normal glass transition temperature.

It will be appreciated that the skins provided in this way may be applied not only to the 'ends' of the cells in the honeycomb structure but may be applied, in addition to the sides of the structure if desired - being affixed to the crests of the corrugations of the outermost layers of the polymer sheets used to form the structure.

If desired additional polymer material may be incorporated in the join between the honeycomb/skin by the interposition between the two parts of a solvent treated (glass transition temperature reduced) pure polymer film as the two parts are brought together.

It will be appreciated that the invention is not limited to the particular hexagonal cell structures described and that cells with other cross sections may be produced using the methods of the invention - see for example the triangular shape cross section cells 86 shown in Figure 5 - simply by varying the shape of the formers and/or heater elements used. It will also be appreciated that the shapes of the cells need not be uniform along their lengths. By appropriately laying up the initial materials and using formers and/or heater elements of the desired shape it is possible to form a structure having, e.g. a pyramidical cell structure as shown at 88 in Figure 6 (which shaows at A a sectional side view and at B a plan view of the structure with the top skin removed).

Prior to applying skins to the honeycomb structure the inner surfaces of it may be treated if desired in any suitable way, e.g. the walls 90 of the cells 88 in the structure shown in Figure 6 may be coated, painted or even metallised as shown to provide a radio wave absorbing structure.

The structures made in accordance with the methods noted above may also be varied by making them non-planar sided, such as is shown in Figure 7. Such a structure may be made either by post-forming a structure made with planar sides (e.g. the structure shown in Figure 4), or by making the original honeycomb core in a tool having a curved bottom wall and using heater elements of decreasing thickness along their lengths and laid up in a 'fan' (Figures 1 and 2) or hung on an arcuate beam and positively guided into the gaps between layers (Figure 3).

As a result of the methods described above it is possible to make not only high temperature polymer impregnated fibres reinforced honeycomb structures but also such structures with skins - that is to say an integrated sandwich structure - which includes no materials other than the matrix polymer and the fibres reinforcement; in particular including no foreign materials such as adhesives.

The honeycomb wall thickness may be as small (0.002" - 0.05mm is obtainable) or as large as desired and if desired other materials such as metallic mesh may be incorporated in the honeycomb and/or any skins applied thereto.

Although described as used with fibres reinforced polymer impregnated materials it will be appreciated that the methods described herein may be used to make honeycomb structures of pure high temperature aromatic polymer materials such as polysulphone, polyethersulphone, polyetherketone, polyetheretherketone, polyetherimide, polyphenelene sulphide, a polyamide or the like.

The solvent used to make the solution of the polymer material to be painted on the mating faces of the layers 12 and/or on the faces of the skins may be any suitable liquid solvent (e.g. for polyethersulphone methylene chloride).

It can be seen that seen that the methods of the present invention enable the manufacture of lightweight honeycomb structures from high temperature thermoplastics materials without the disadvantages of the known low temperature foamed thermosetting or thermoplastic materials. With the methods now described it is possible to achieve ready variation of the shape of the 'cell' within the structure, ensure the interstices of the cells are fully loaded with polymer material, and to readily make honeycomb structures from fibre reinforced thermoplastics materials, to which, if desired, a pre-formed skin or skins may be attached to form an integrated composite, sandwich structure without use of adhesive.

CLAIMS

1. A method of making a high temperature polymer honeycomb structure comprising the steps of positioning in a tool layers of the high temperature polymer material with interposed shaped formers, applying heat and applying pressure to the tool sufficient to cause the polymer material in different layers to coalesce, cooling the polymer and removing the resultant honeycomb structure so formed.

2. A method as claimed in claim 1, wherein the high temperature polymer material is one of polysulphone, polyethersulphone, polyetherketone, polyetheretherketone, polyetherimide, polyphenelene sulphide, a polyamide or the like.

3. A method as claimed in claim 1 or claim 2, wherein the high temperature polymer material is reinforced with glass, carbon, quartz, boron or other fibres reinforcing fibres.

4. A method as claimed in any one of the preceding claims, wherein the layers of thermoplastics material are un-formed and heat is applied to raise the temperature of the thermoplastics material to a level at which the thermoplastics material is moulded to form the honeycomb structure.

5. A method as claimed in any one of claims 1 to 3, wherein the thermoplastics material is pre-formed and is laid up in the tool with touching surfaces thereof coated with a solution of the polymer material and heat is applied to raise the temperature of the touching surfaces of the layers of thermoplastics material to a level at which those touching surfaces fuse to form the honeycomb structure.

6. A method according to any one of the preceding claims, wherein the formers are hollow tubes and heating of the tool is effected in an oven.

7. A method according to any one of claims 1 to 5, wherein at least some of the formers are electrical heating elements by which heat is applied to the polymer material, other of the formers being hollow metal tubes.

8. A method as claimed in claim 7 or claim 8, wherein air is passed through the said tubes to aid the heating and cooling of the polymer material.

9. A method according to any one of the preceding claims, wherein the tool is used to apply heat and

pressure sequentially to adjacent sections of the laid up polymer layers therein.

10. A method according to claim 9, wherein the honeycomb structure is made continuously, lengths of the polymer layers being passed sequentially to the tool in which they are laid up and formed into sections of honeycomb structure.

11. A method according to any one of the preceding claims, wherein the walls of the cells of the honeycomb structure are metallised after formation.

12. A method according to any one of the preceding claims, wherein one or more layers of high temperature polymer material are affixed to the honeycomb structure by painting a surface of the or each layer with a solution of the polymer material therein, the painted surface of said layer thereafter being brought into contact with the honeycomb structure with application of heat and pressure.

13. A method according to claim 11, wherein the polymer material of the or each layer is the same as the polymer material of the honeycomb structure.

14. A method as claimed in any one of the preceding claims and as described herein with reference to the accompanying drawings.

15. A lightweight high temperature thermoplastics material honeycomb structure made in accordance with the method of any one of the preceding claims.

16. Apparatus for use in the manufacture of the a lightweight high temperature thermoplastics material honeycomb structure substantially as herein described with reference to Figures 1 and 2, or Figure 3 of the accompanying drawings.

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