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(54) COMPOSITE BUILDING COMPONENTS

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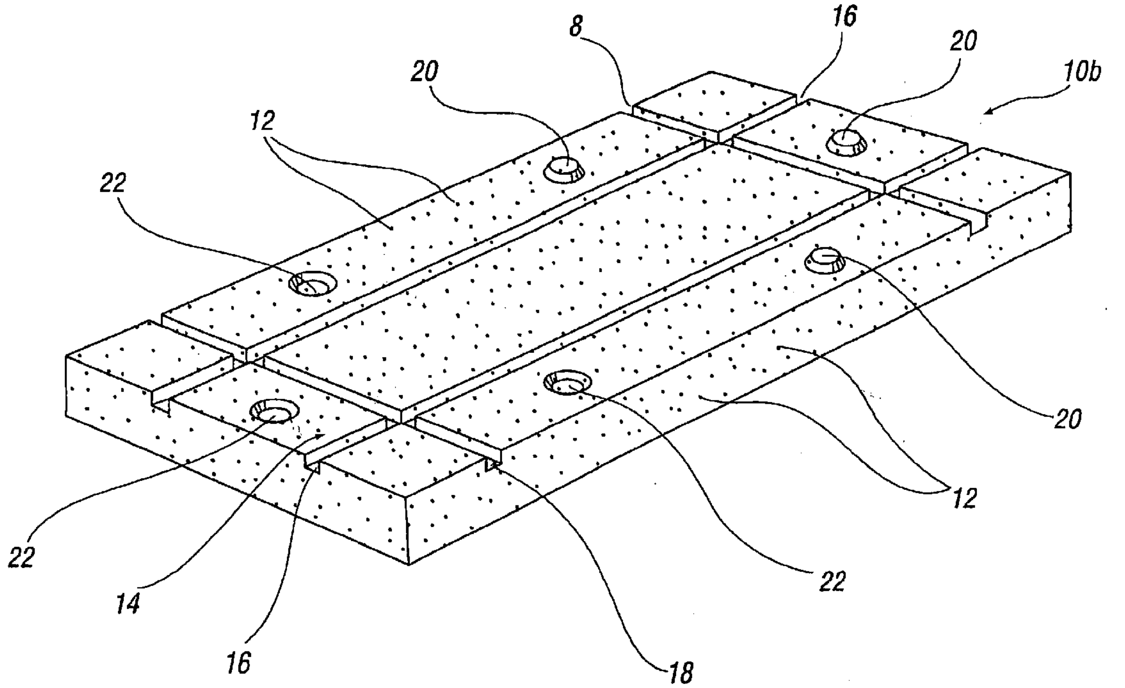
(57) **ABSTRACT**

A structural insulated panel having a core (**40**) of expanded polystyrene sandwiched between, and bonded to, two facings (**52**). The facings are attached to faces of the core formed by moulding. Preferably the core is an expanded polymer moulding and the preferred polymer is polystyrene. The panel is useful as a building component.



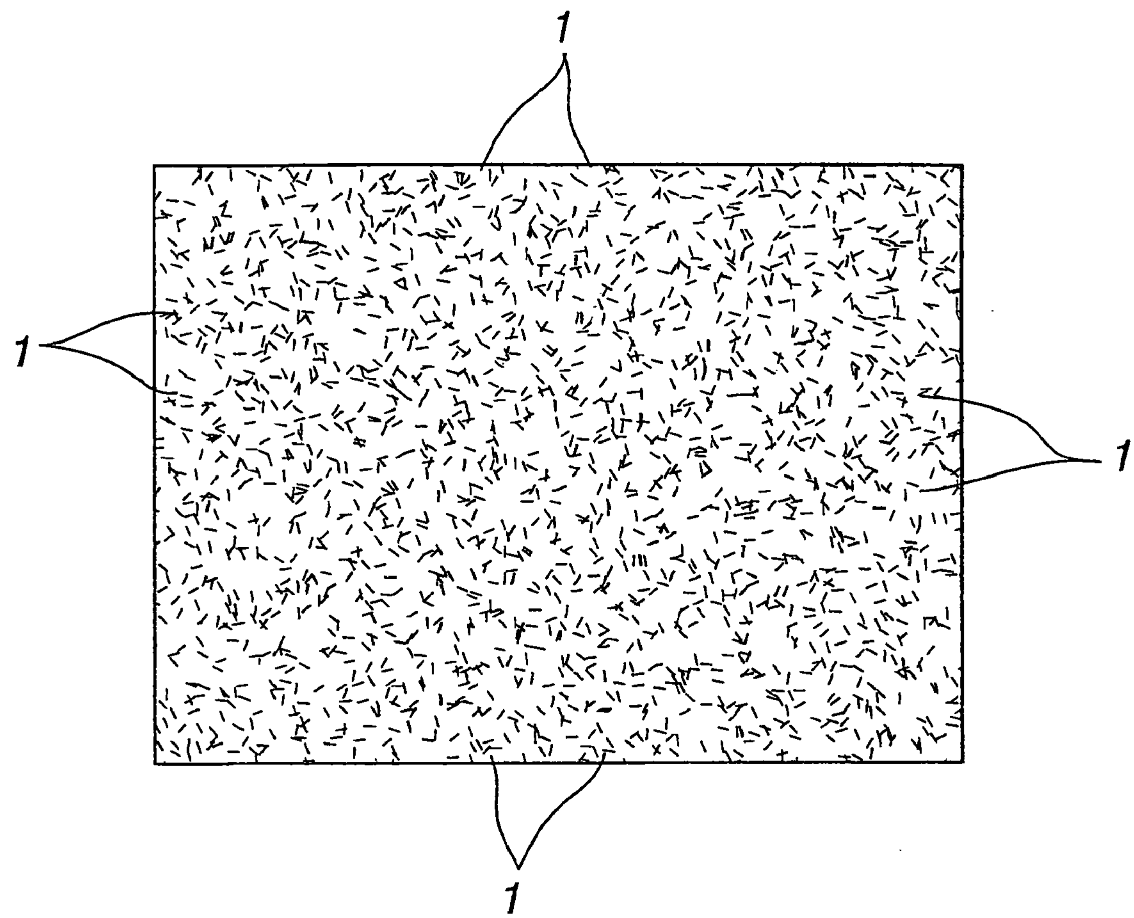


FIG. 1

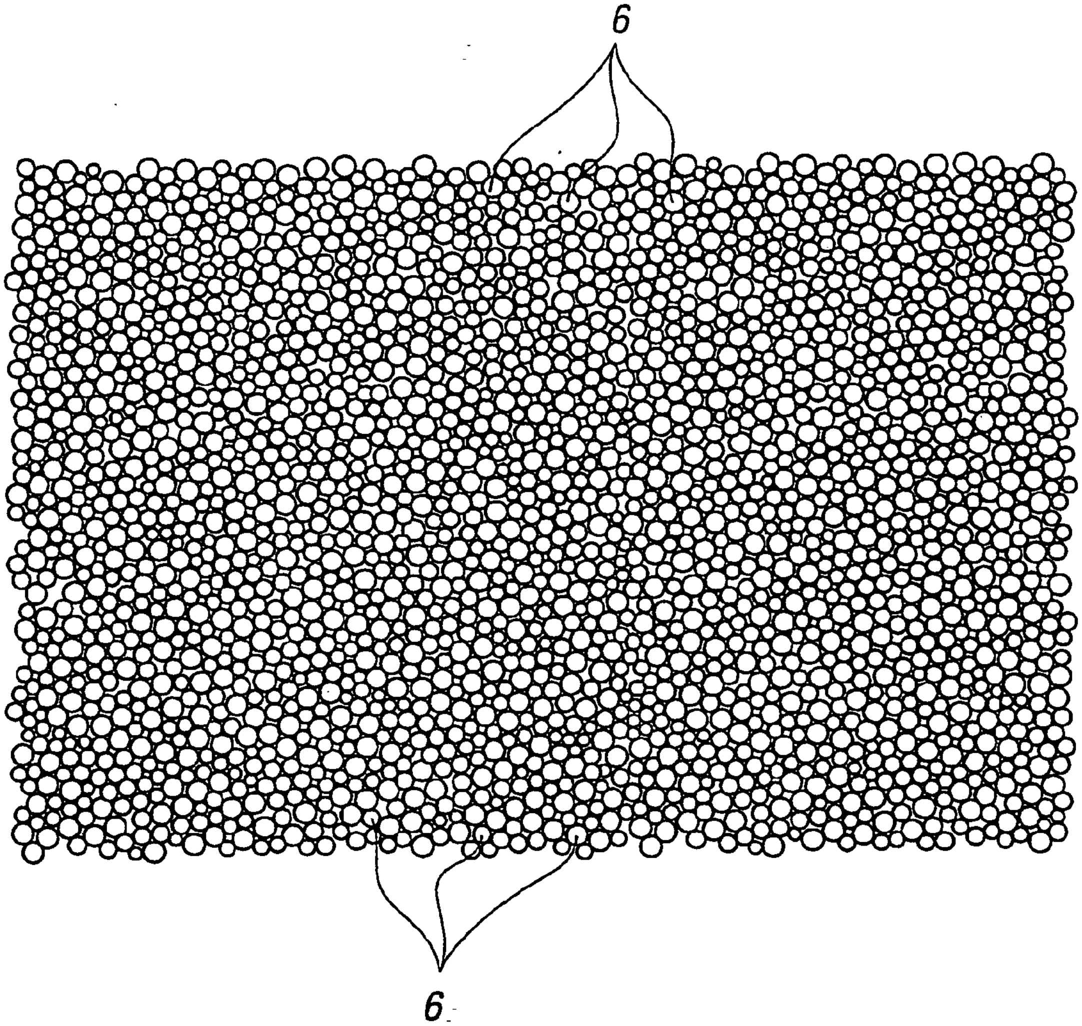


FIG. 2

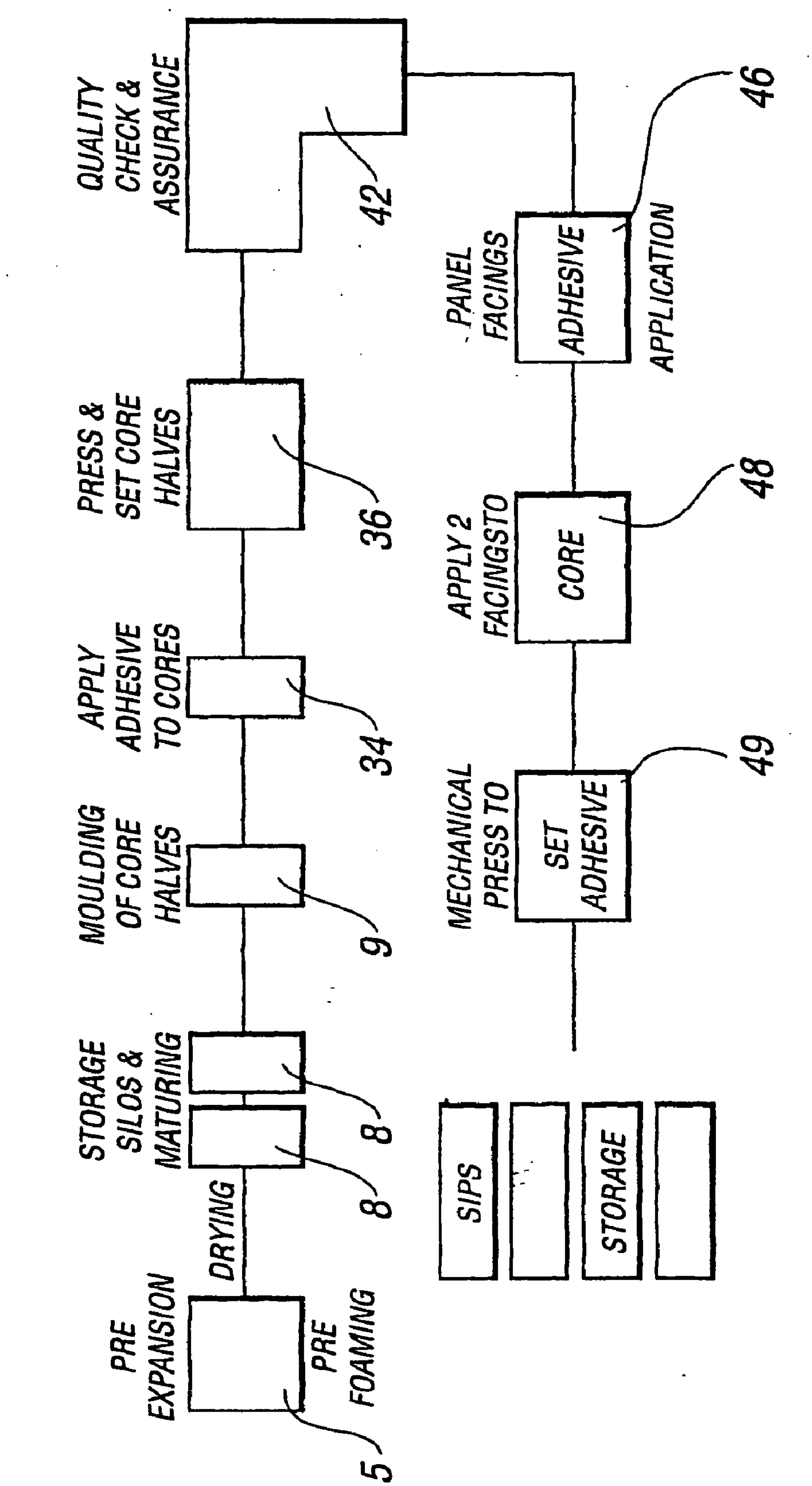

PRE EXPANSION
PRE FOAMING
5
DRYING
STORAGE SILOS & MATURING
8
8
MOULDING OF CORE HALVES
9
APPLY ADHESIVE TO CORES
34
PRESS & SET CORE HALVES
36
QUALITY CHECK & ASSURANCE
42
PANEL FACINGS
ADHESIVE
APPLICATION
46
APPLY 2 FACINGSTO
CORE
48
MECHANICAL PRESS TO
SET ADHESIVE
49
SIPS
STORAGE

FIG. 3

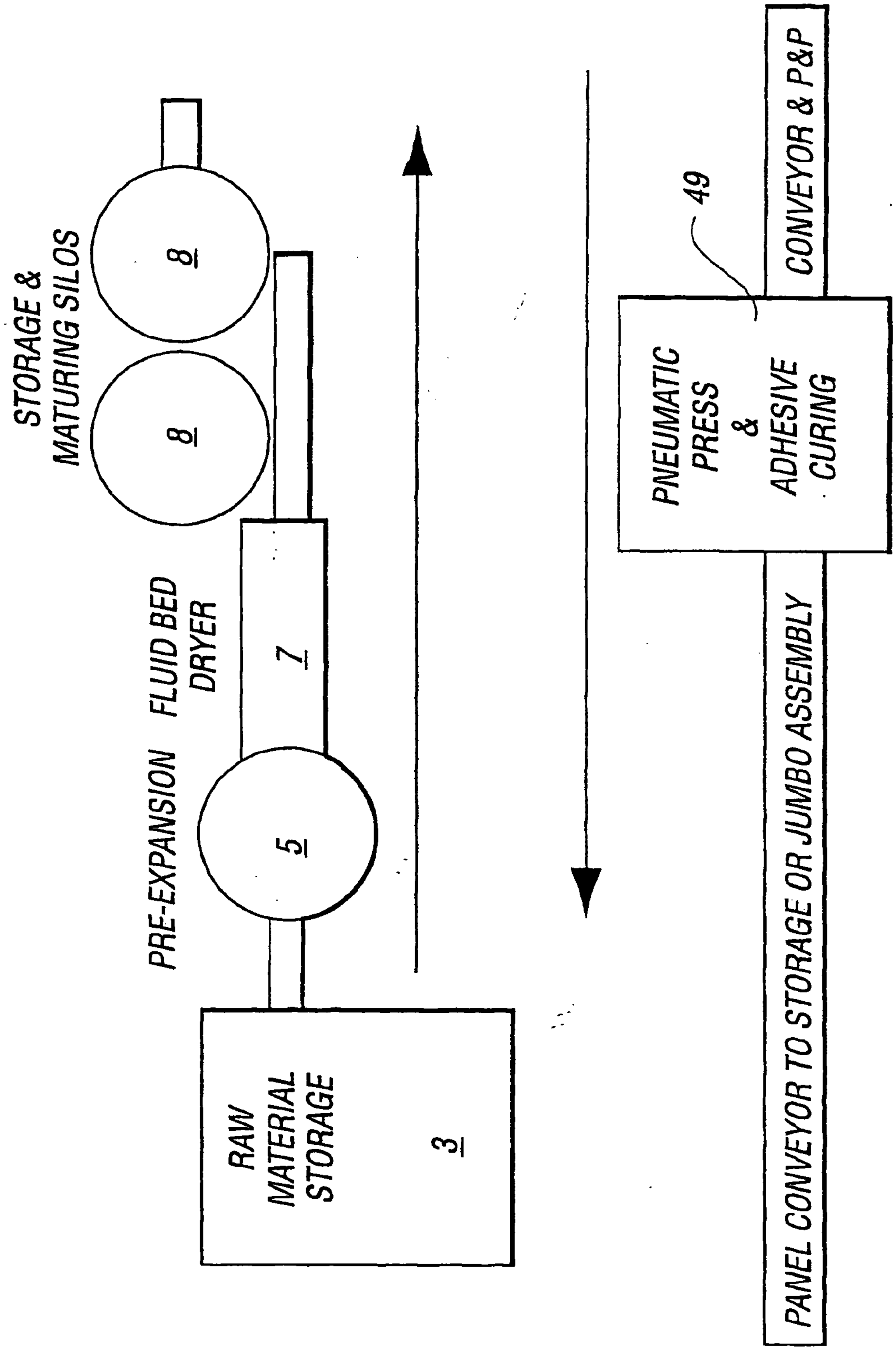

RAW MATERIAL STORAGE
3
PRE-EXPANSION
5
FLUID BED DRYER
7
STORAGE & MATURING SILOS
8
8
PNEUMATIC PRESS & ADHESIVE CURING
49
CONVEYOR & P&P
PANEL CONVEYOR TO STORAGE OR JUMBO ASSEMBLY

FIG. 4

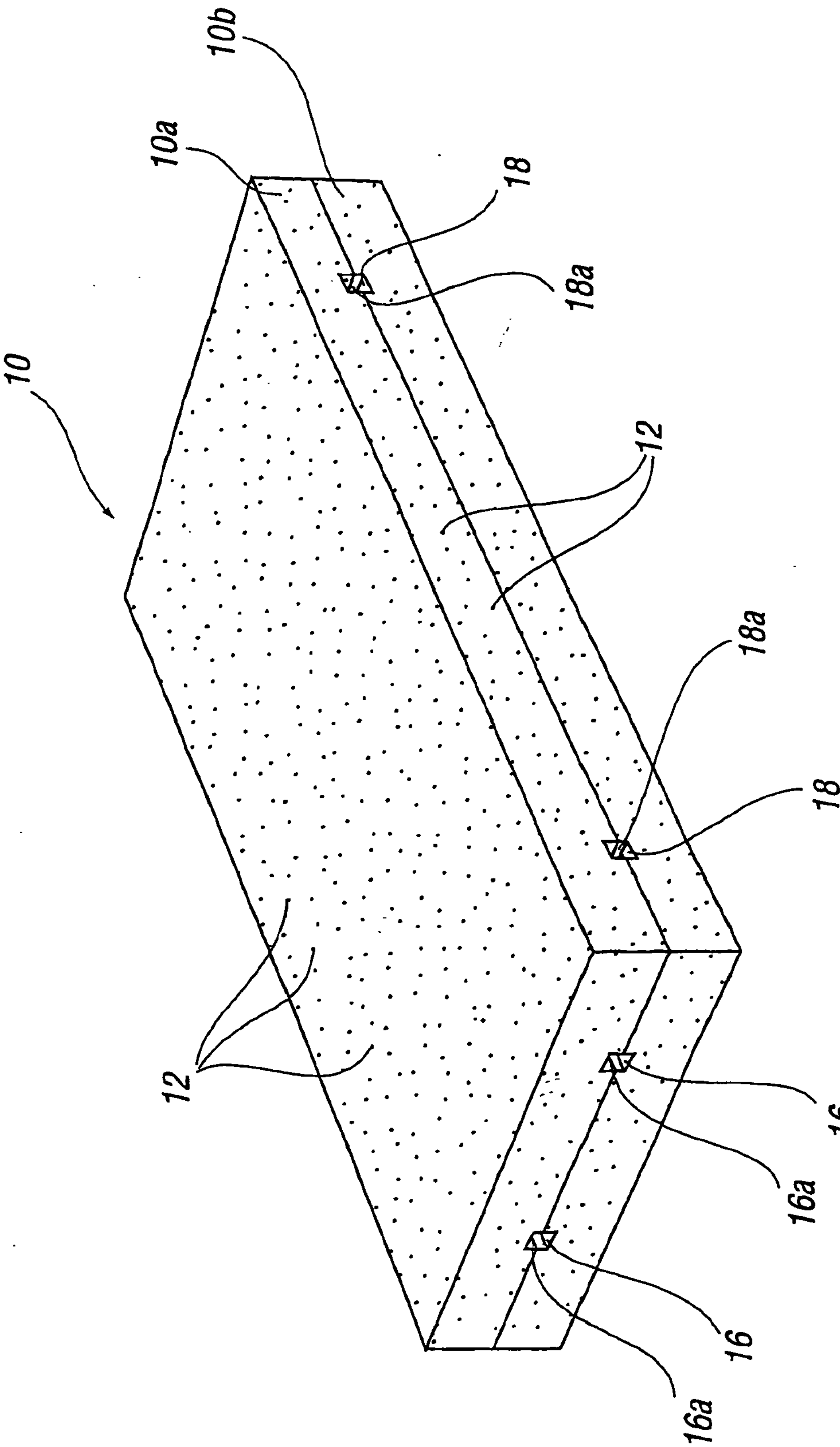


FIG. 5

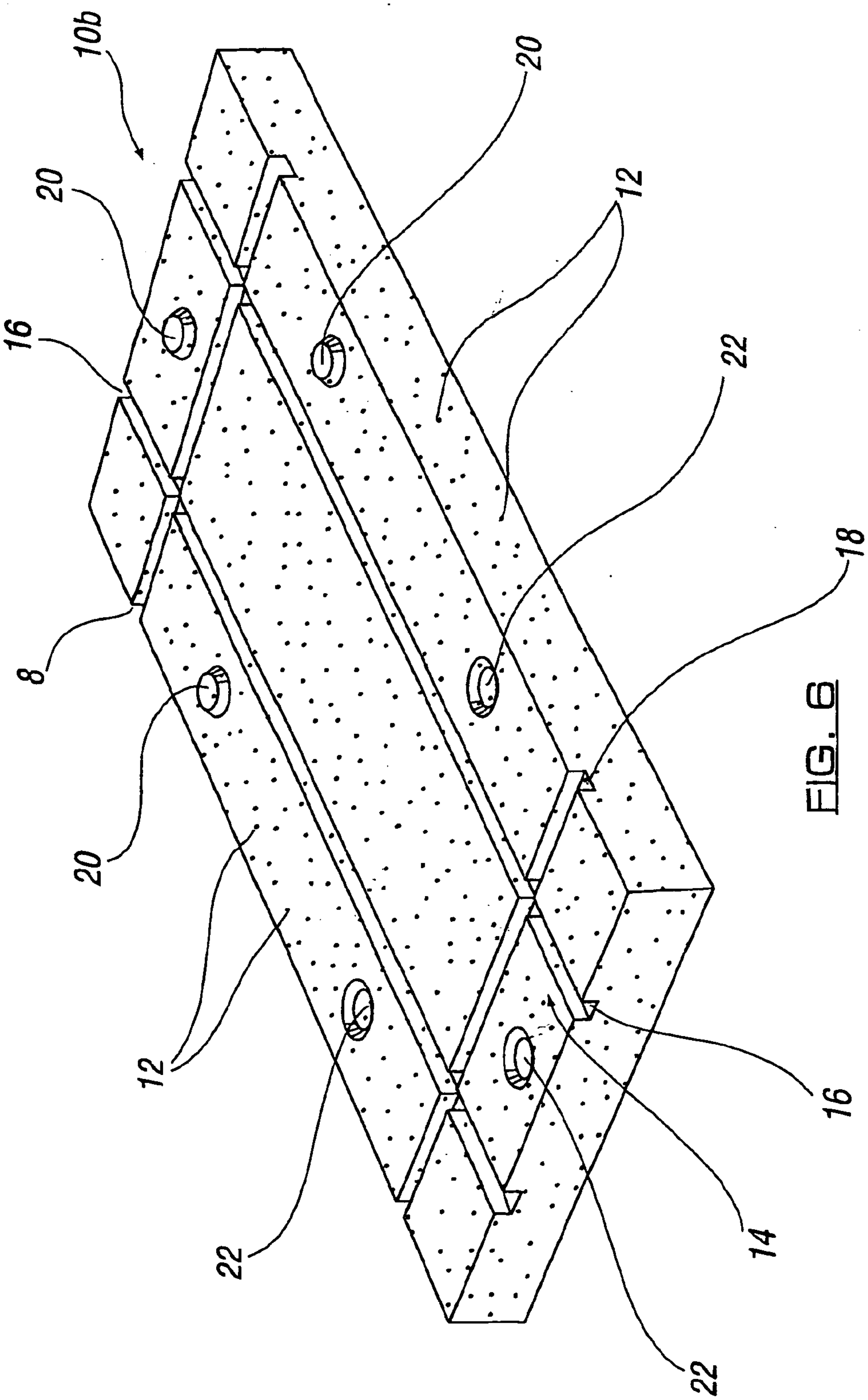


FIG. 6

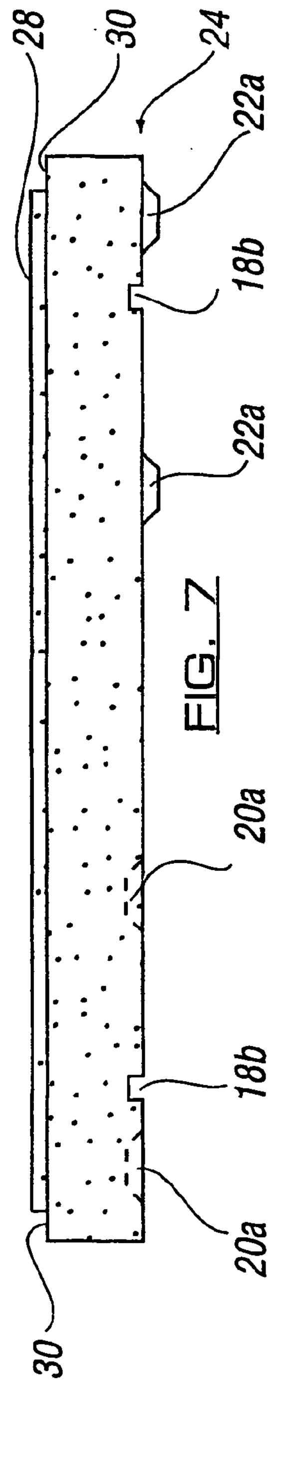

28
30
24
22a
18b
22a
20a
18b
20a
30

FIG. 7

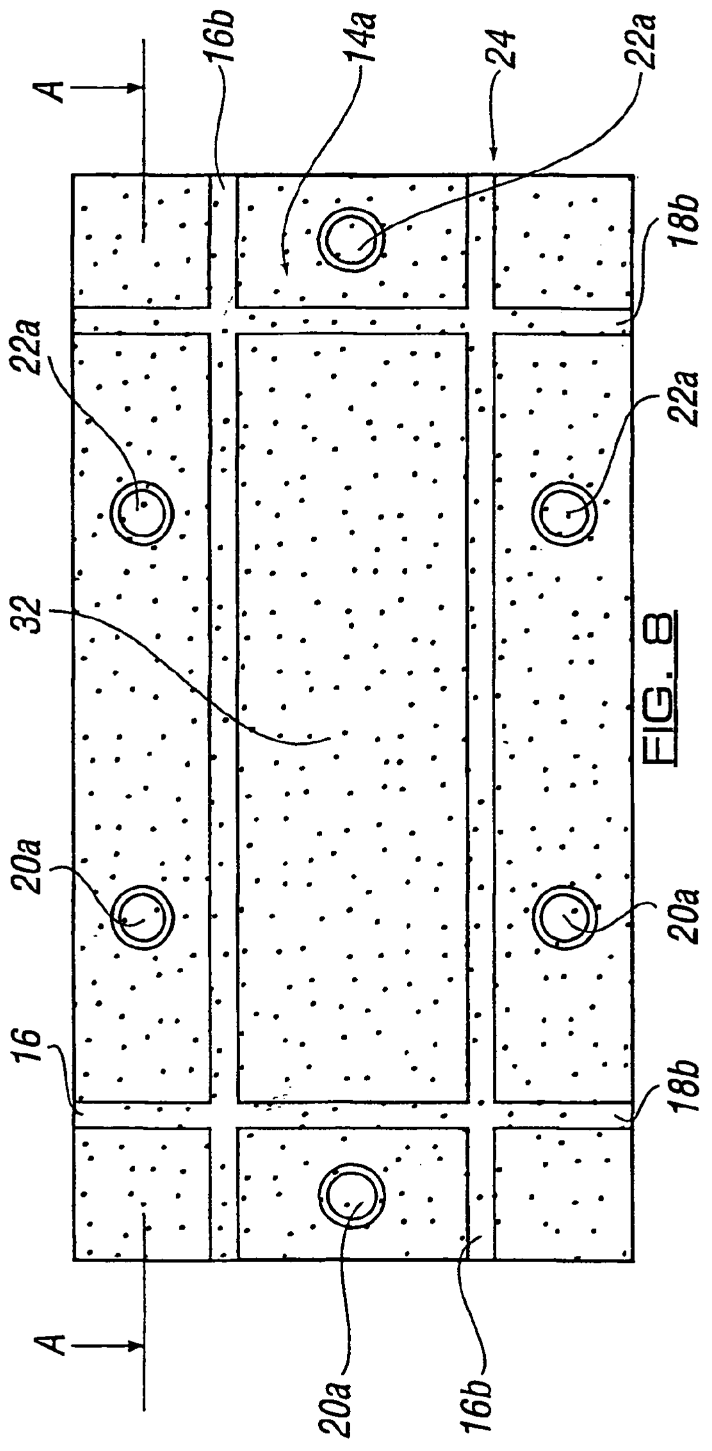

A
16b
14a
24
22a
18b
22a
22a
32
20a
20a
16
18b
A
20a
16b

FIG. 8

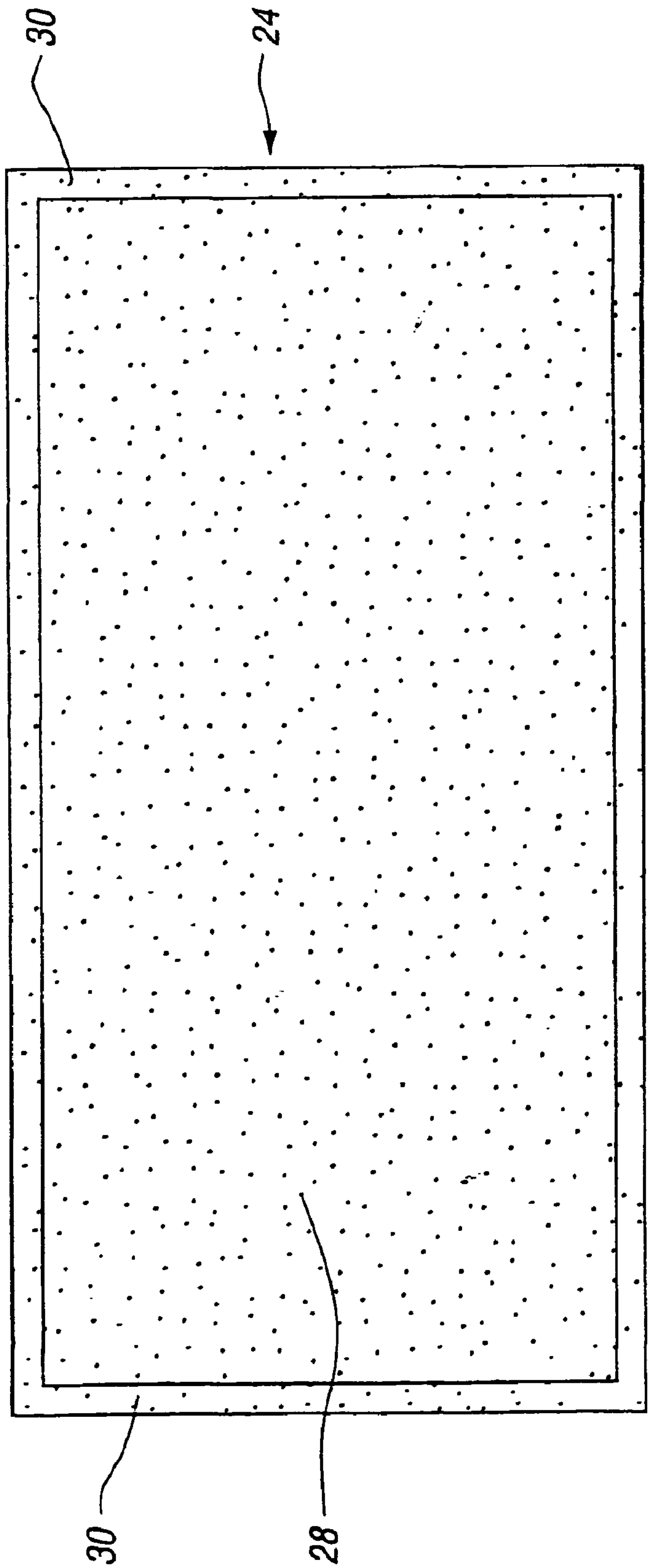


FIG. 9

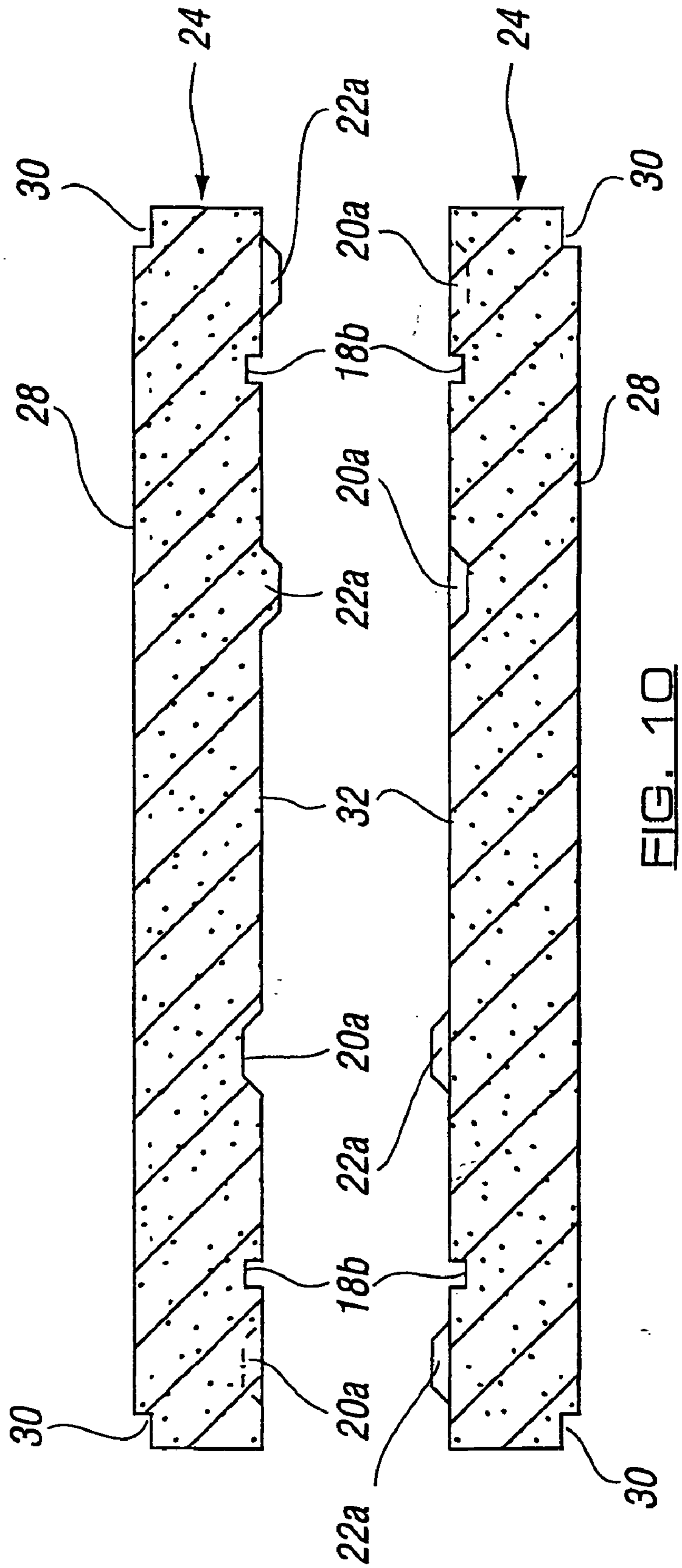


FIG. 10

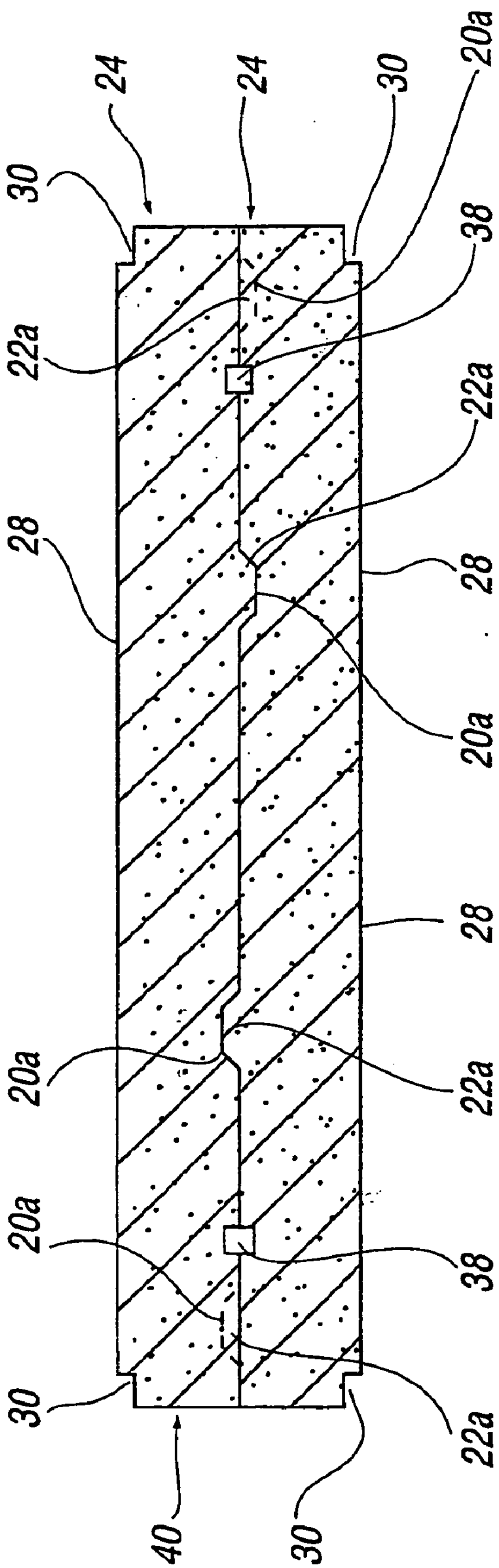


FIG. 11

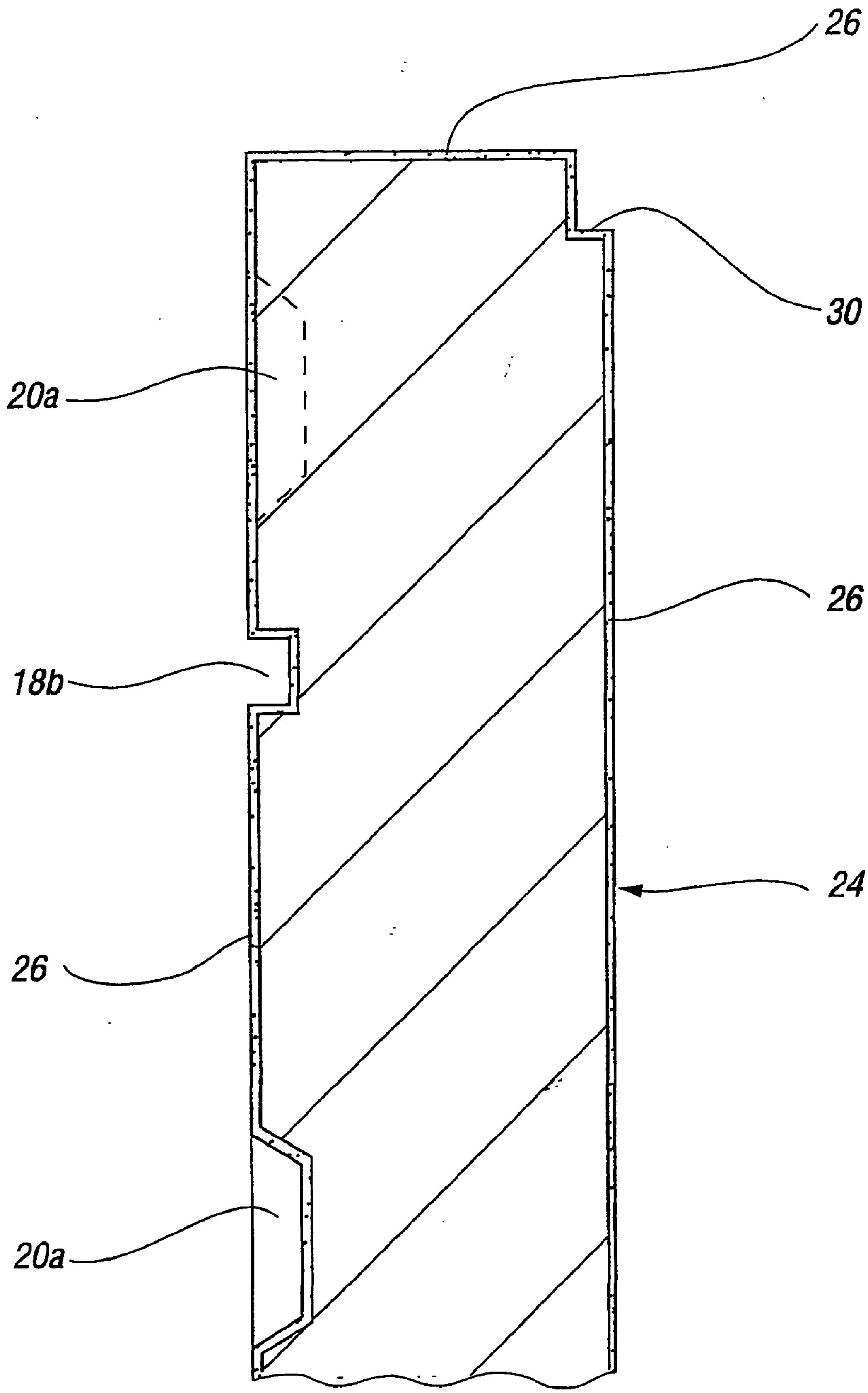


FIG. 12

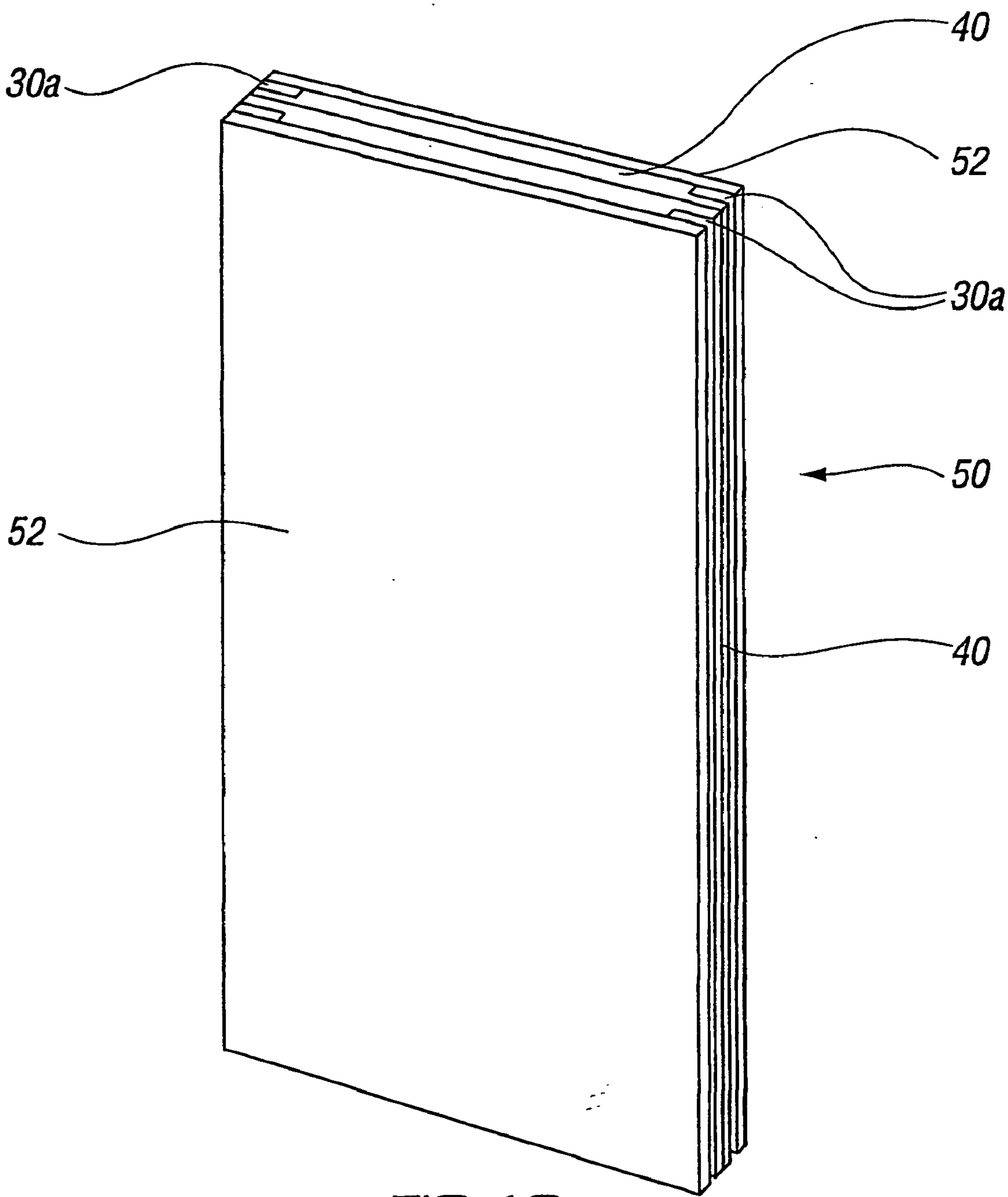


FIG. 13

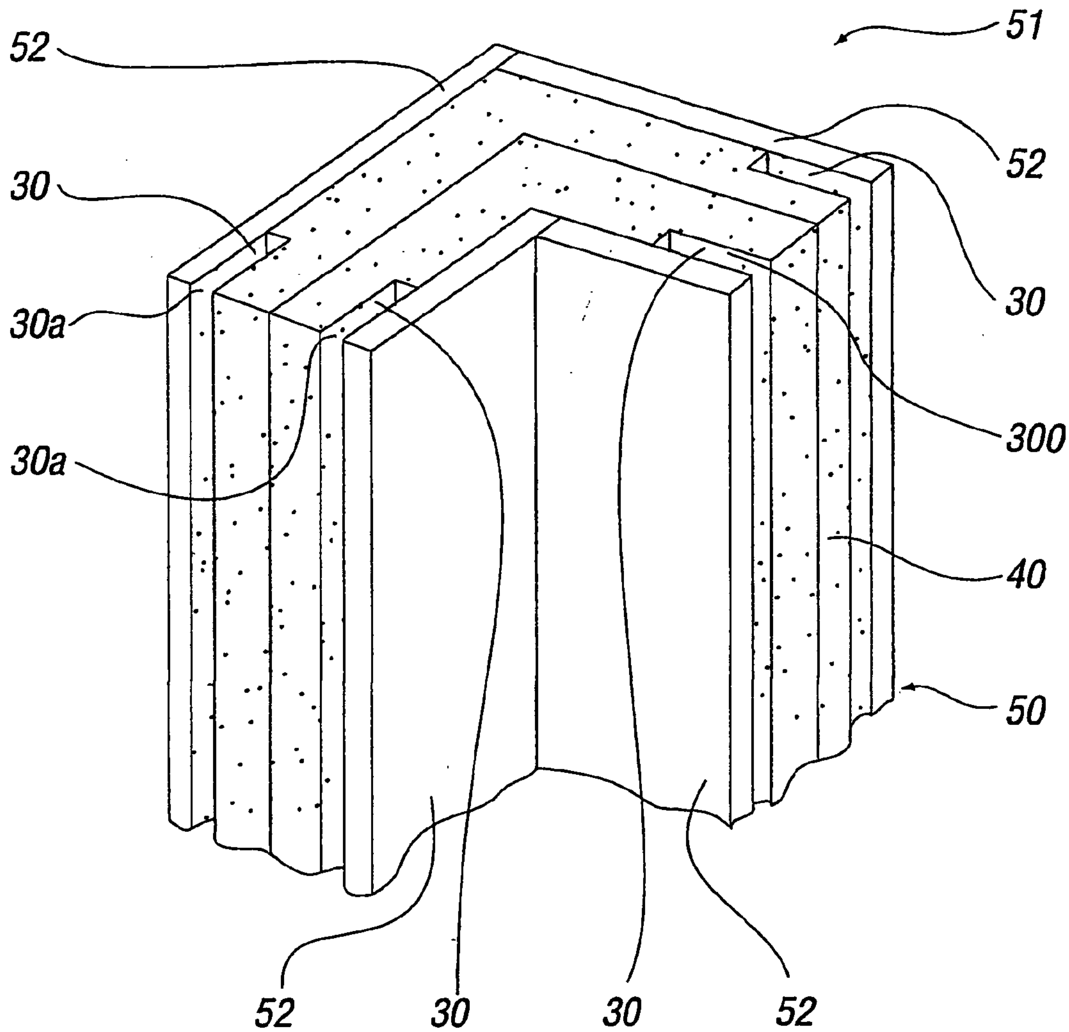


FIG. 14

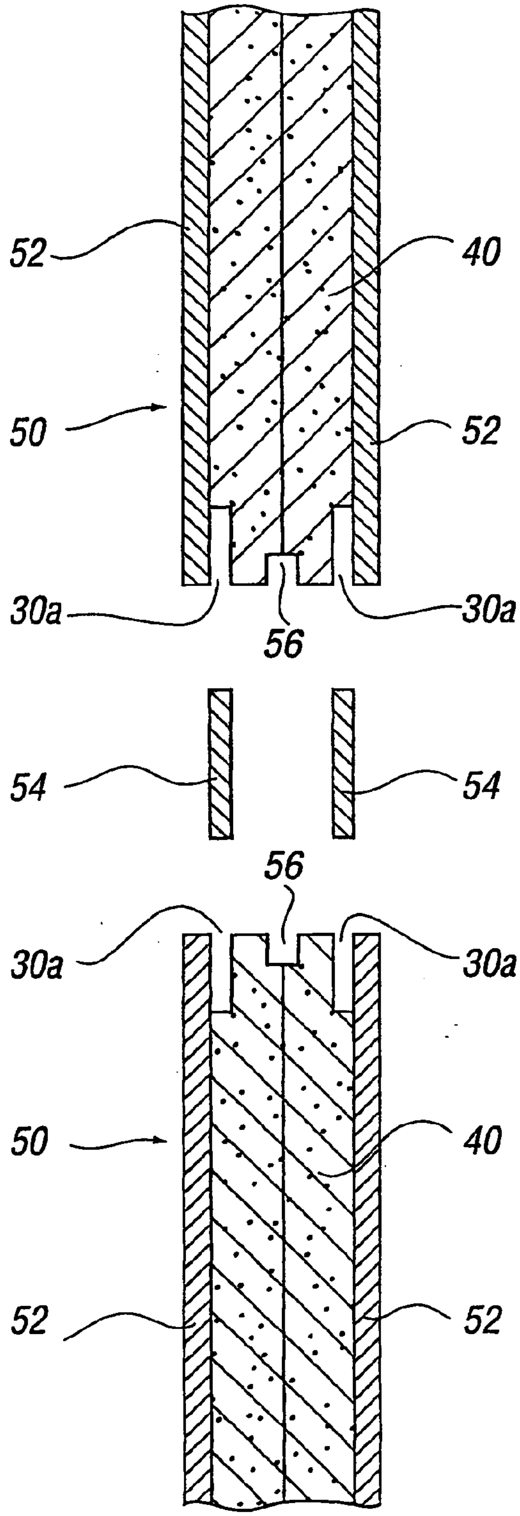

52
40
50
52
30a
56
30a
54
54
56
30a
30a
50
40
52
52

FIG. 15

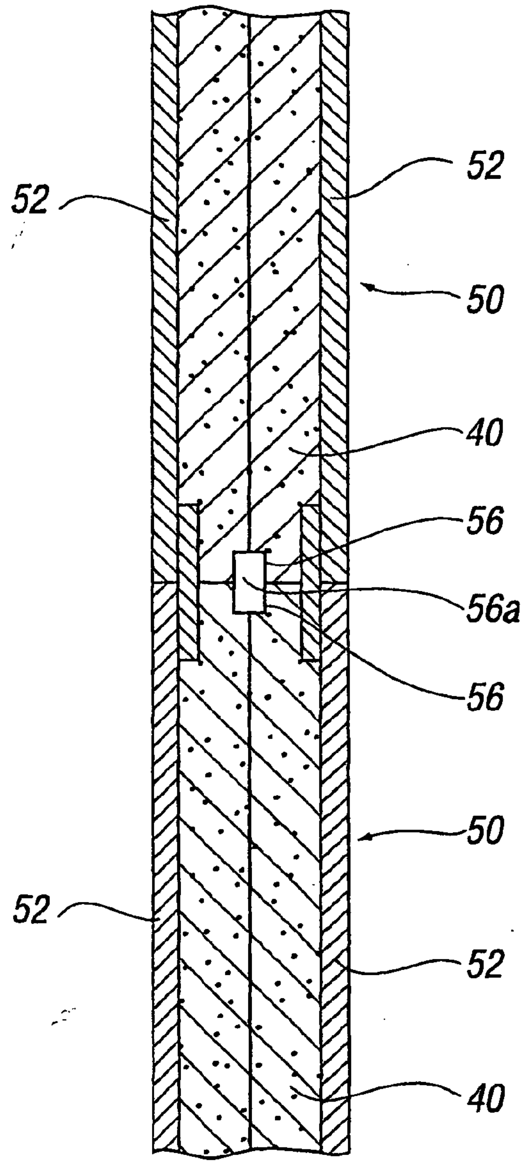

52
52
50
40
56
56a
56
50
52
52
40

FIG. 16

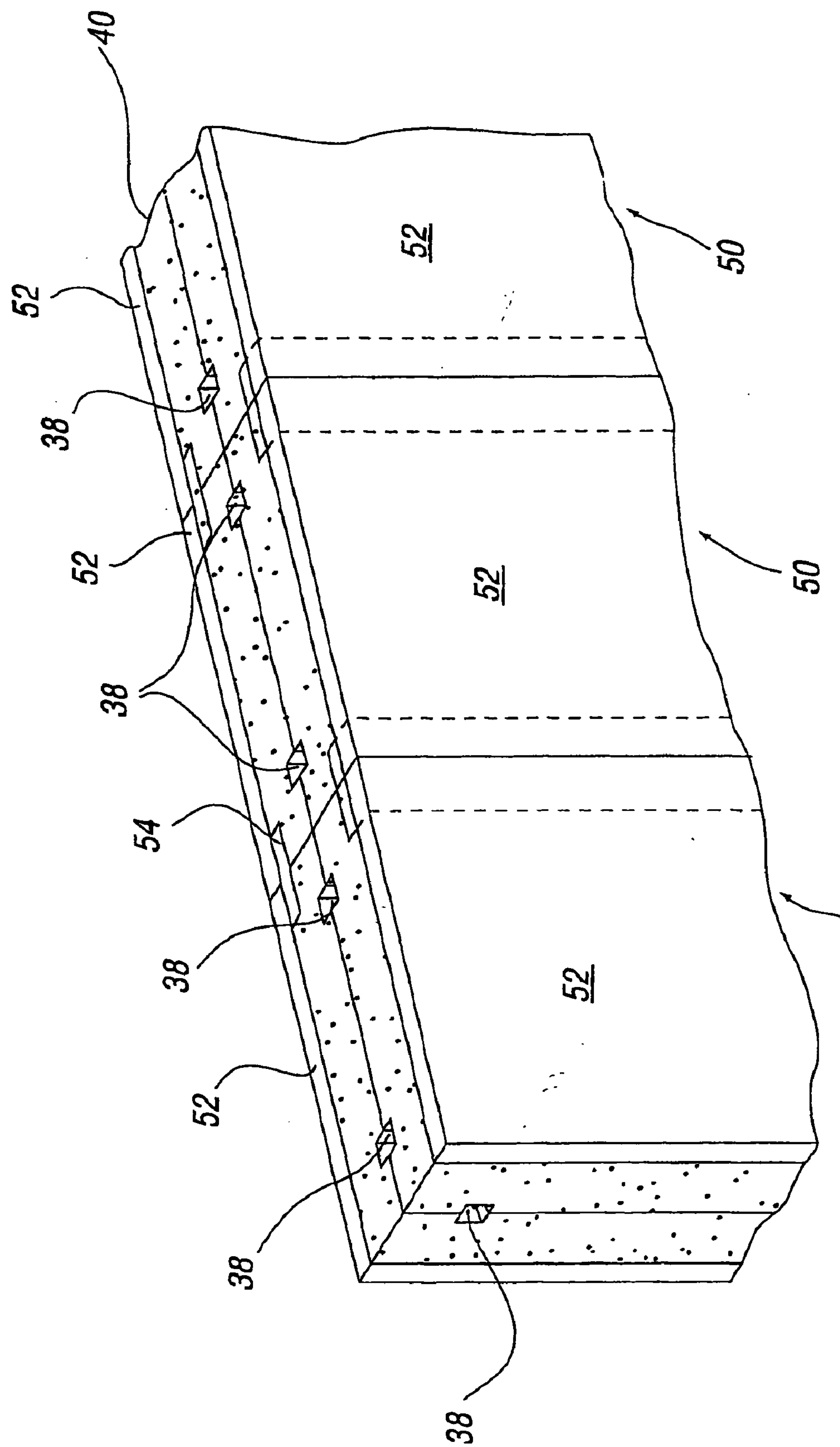
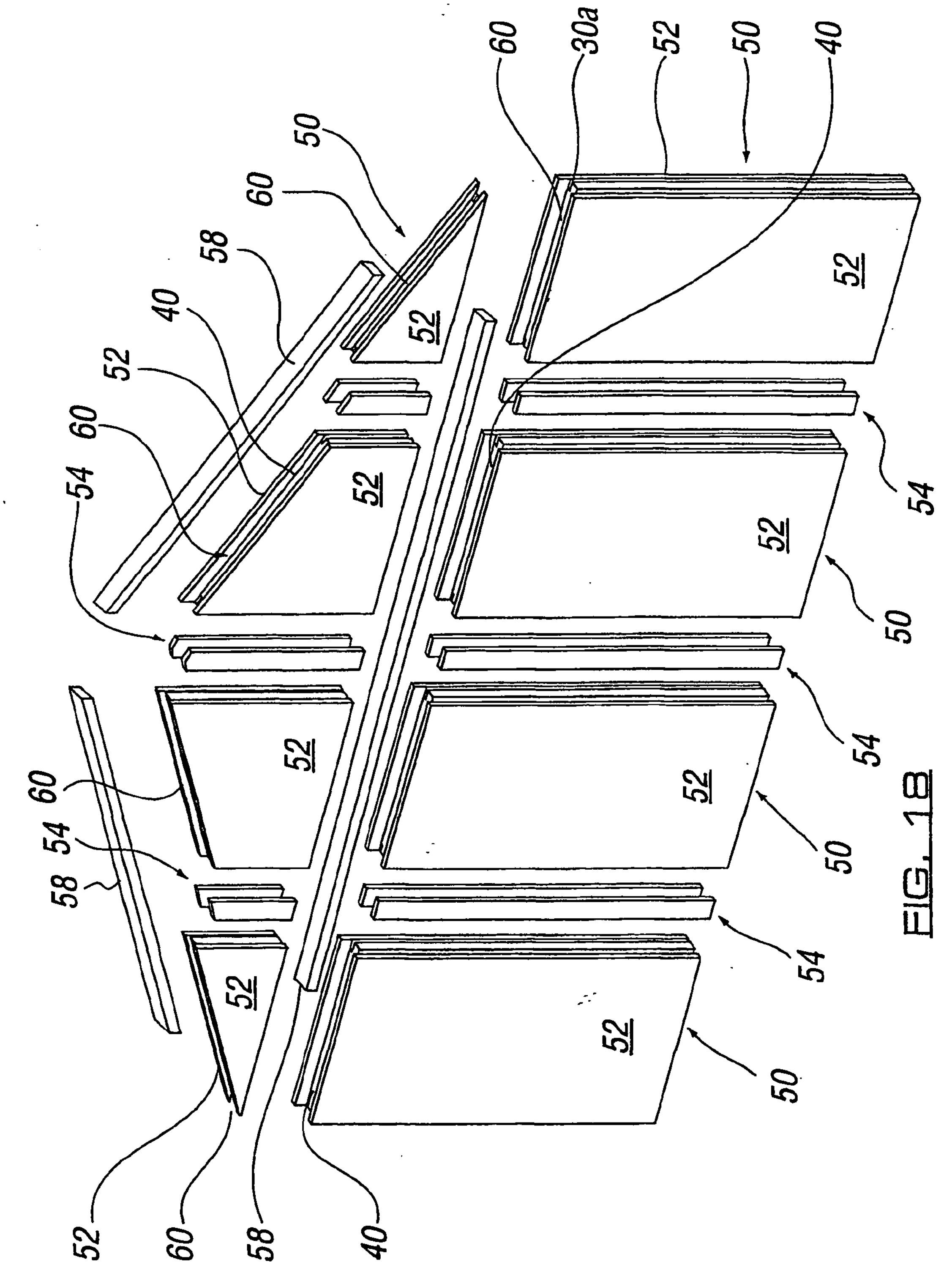


FIG. 17



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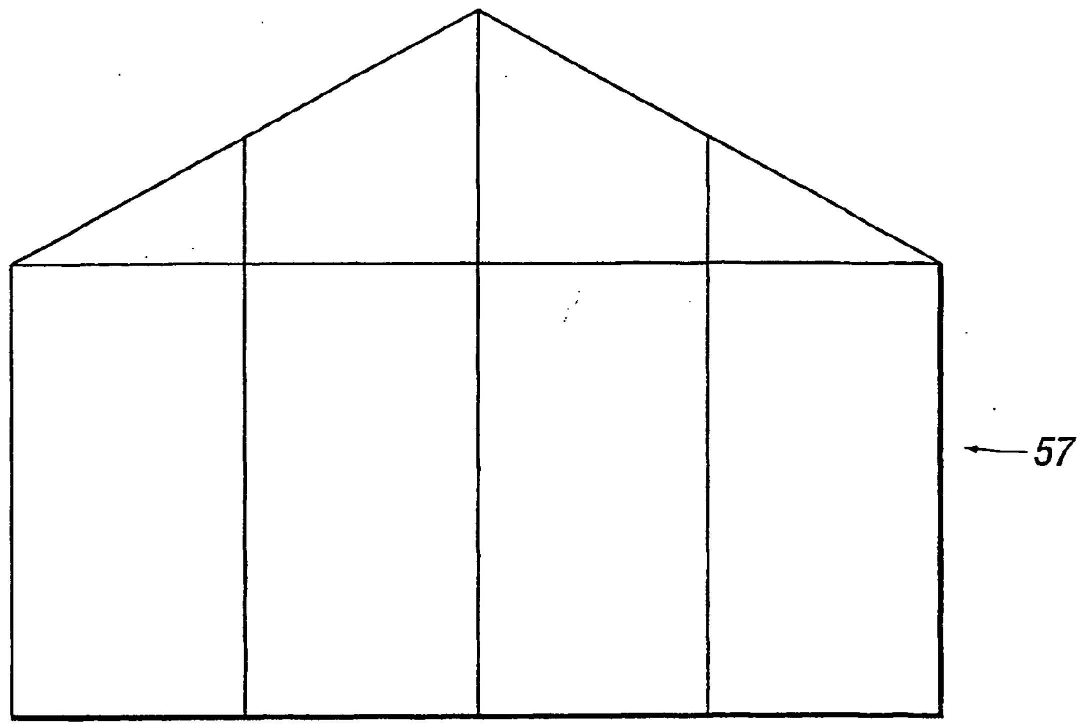


FIG. 18A

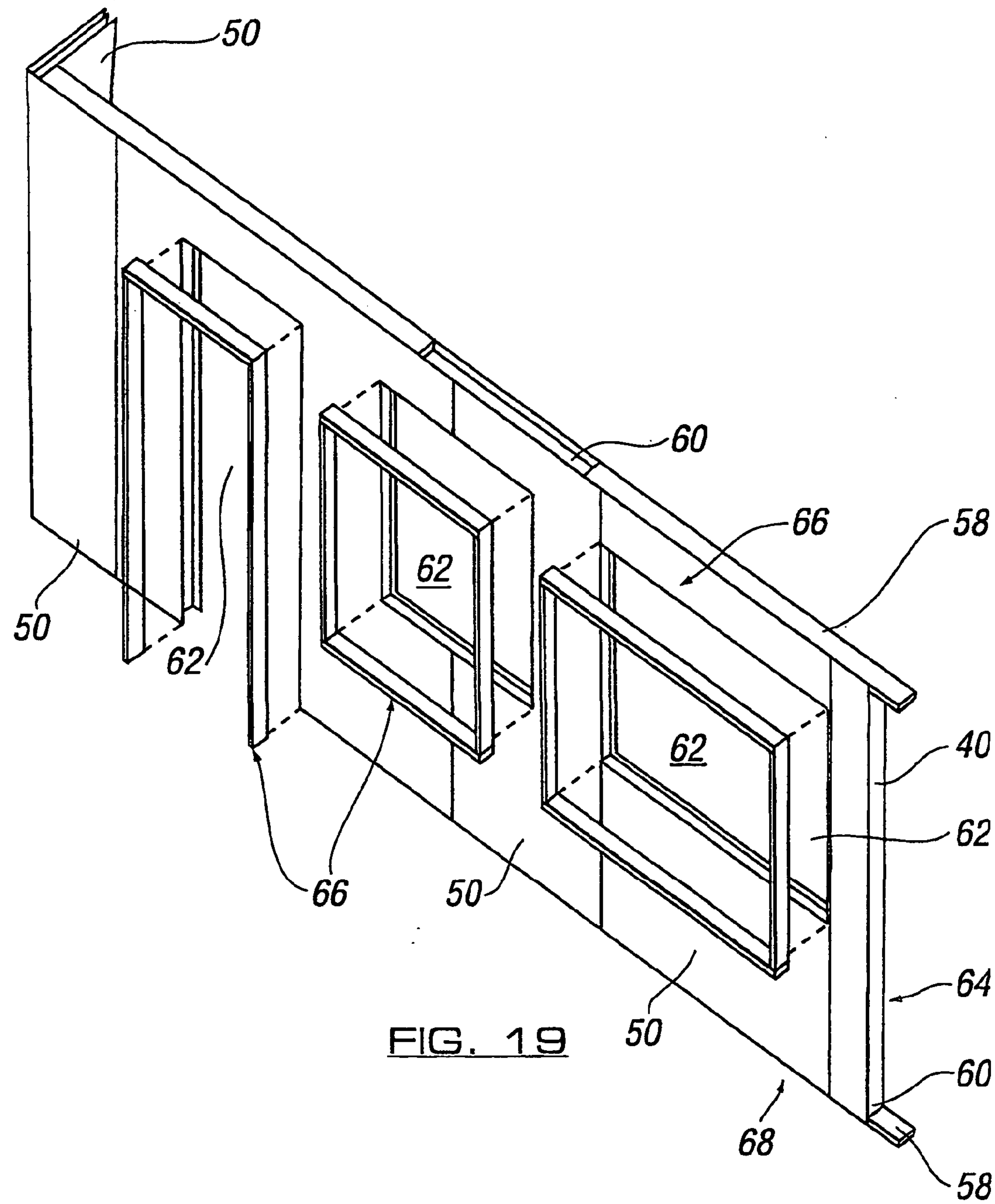


FIG. 19

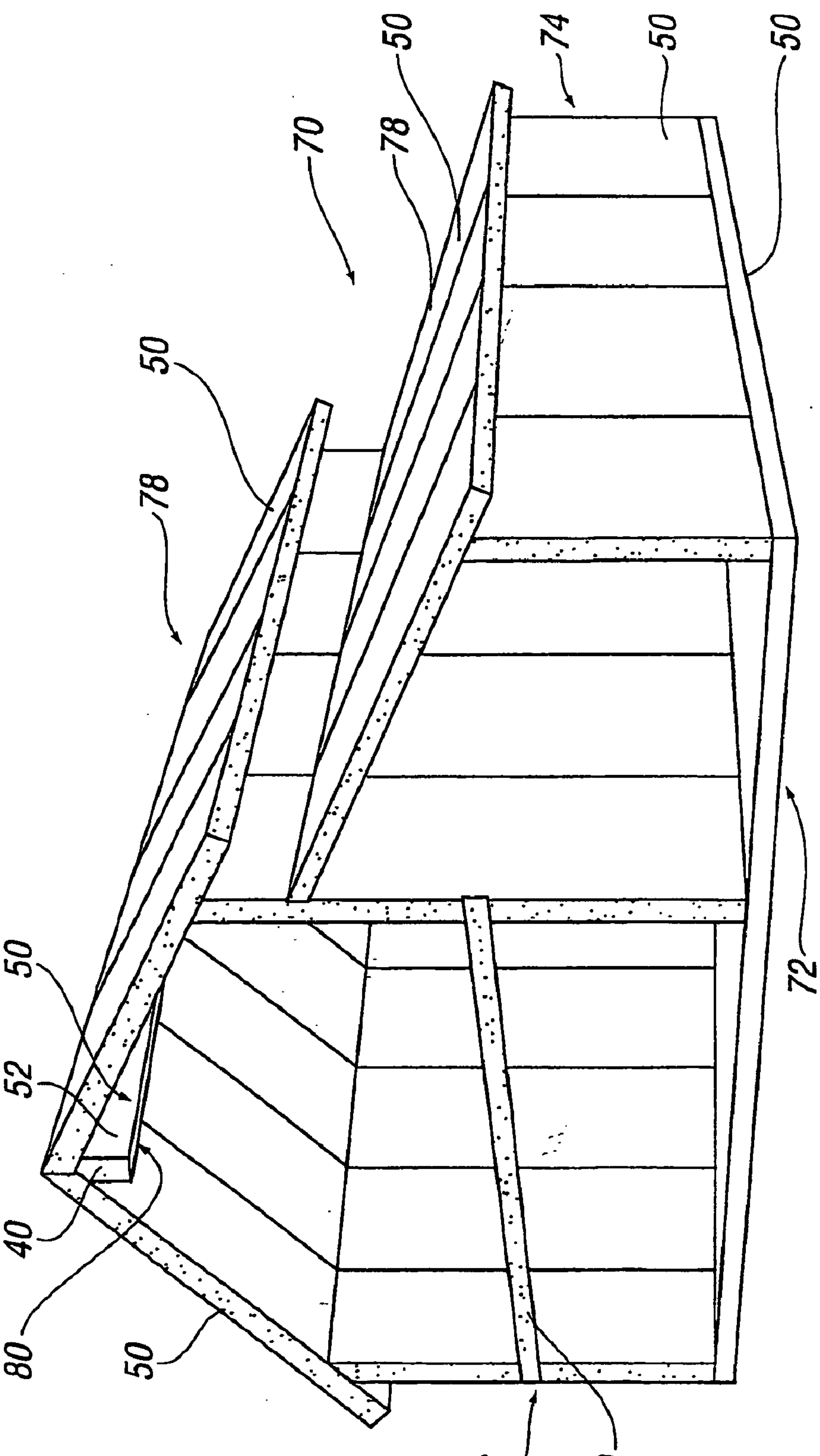
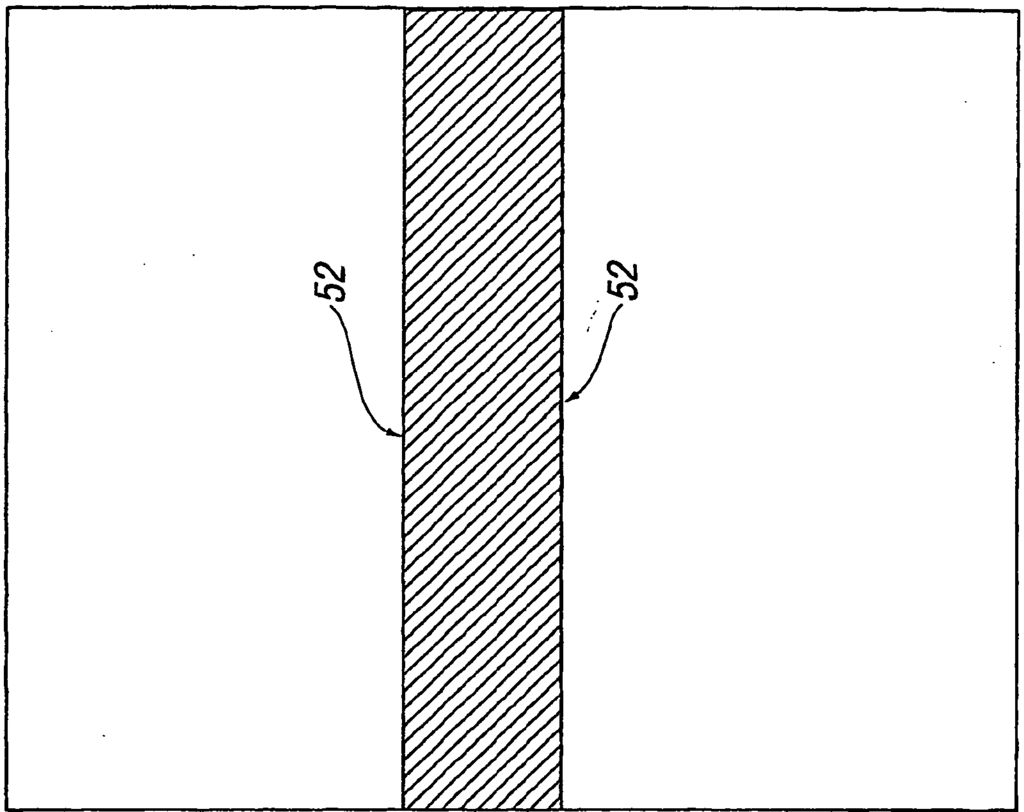


FIG. 20



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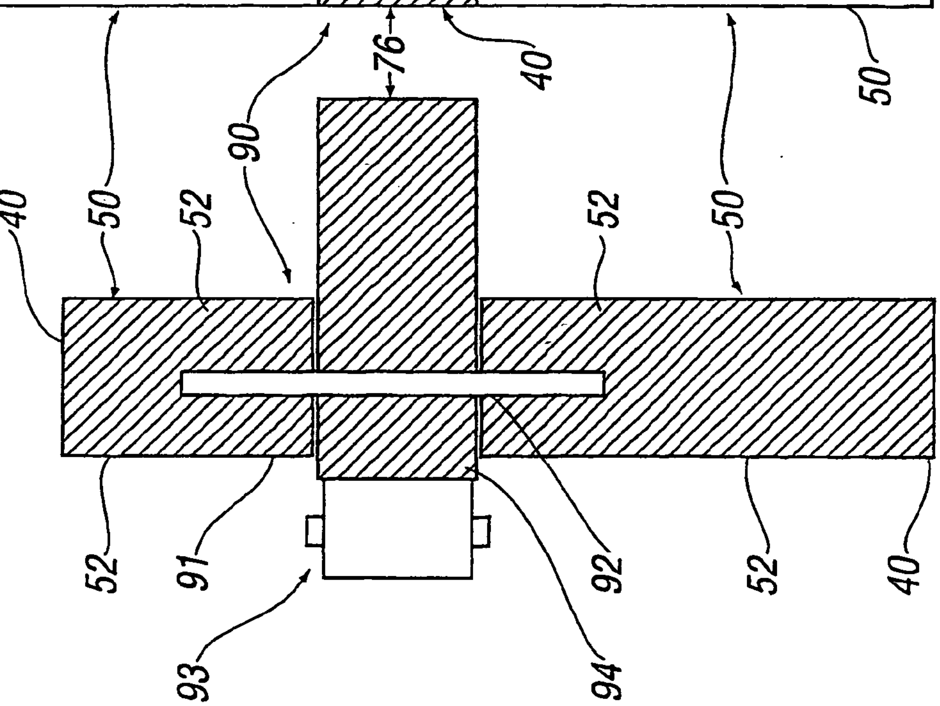

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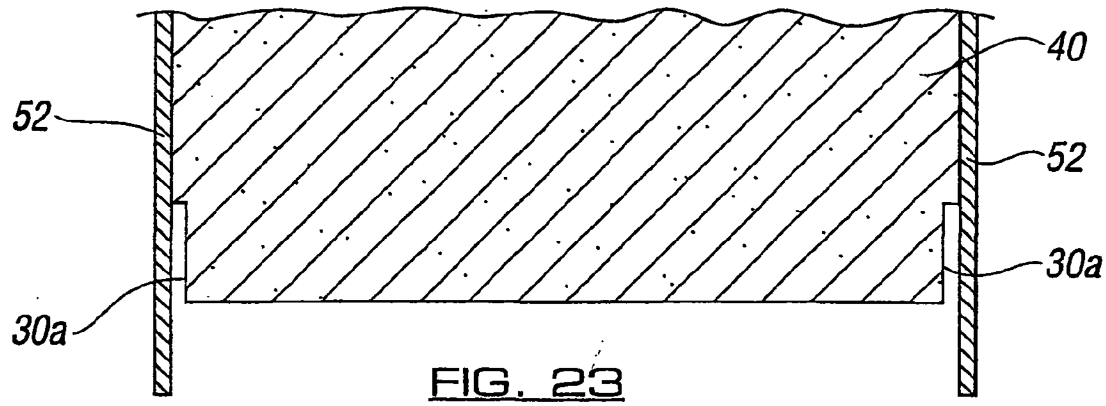

FIG. 23

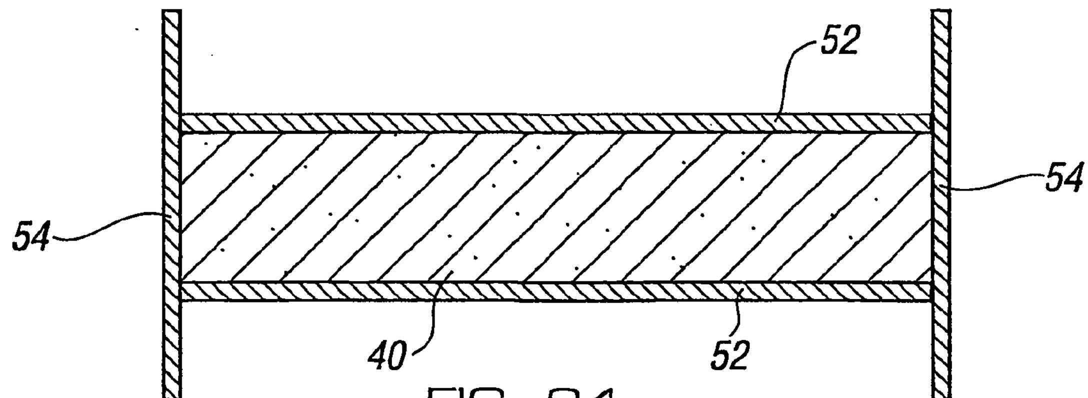

FIG. 24

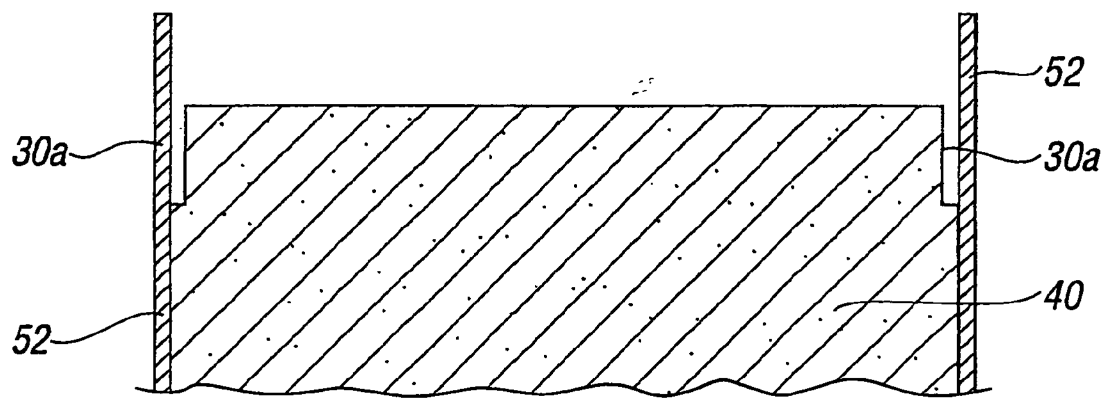

FIG. 25

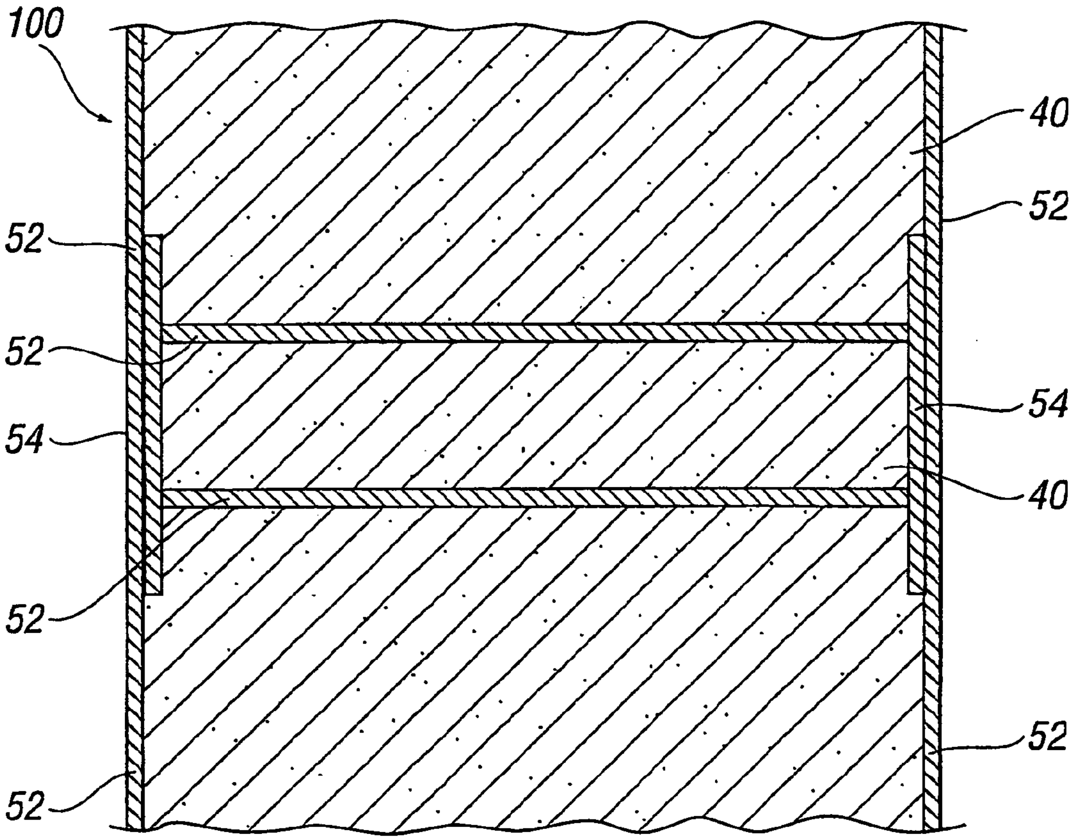

FIG. 26

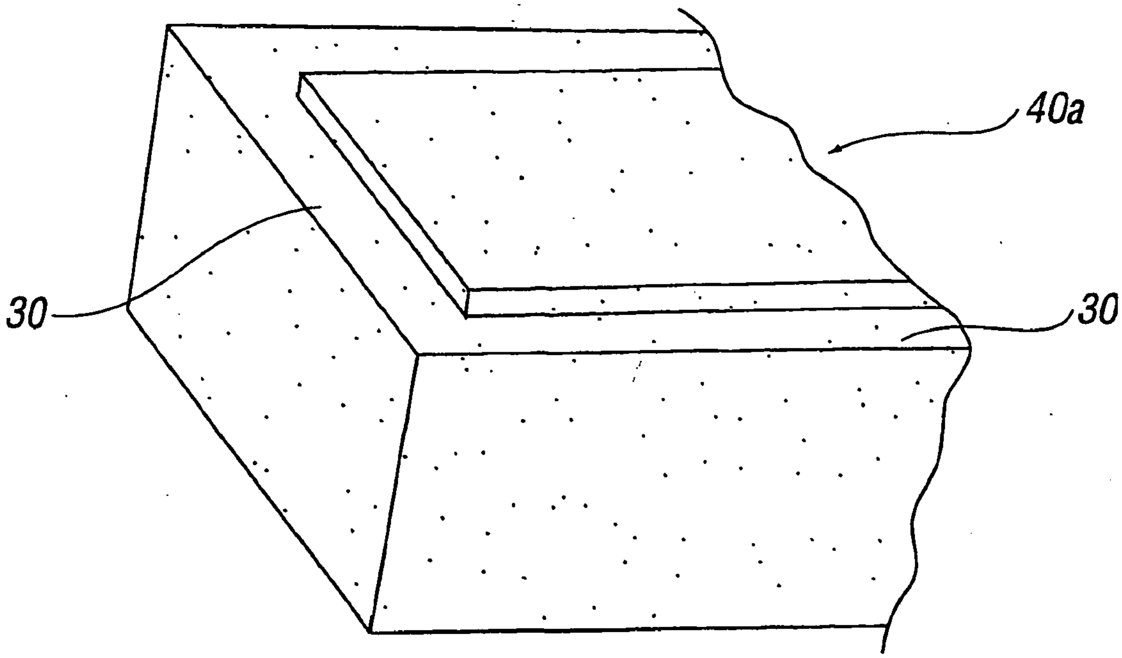

FIG. 27

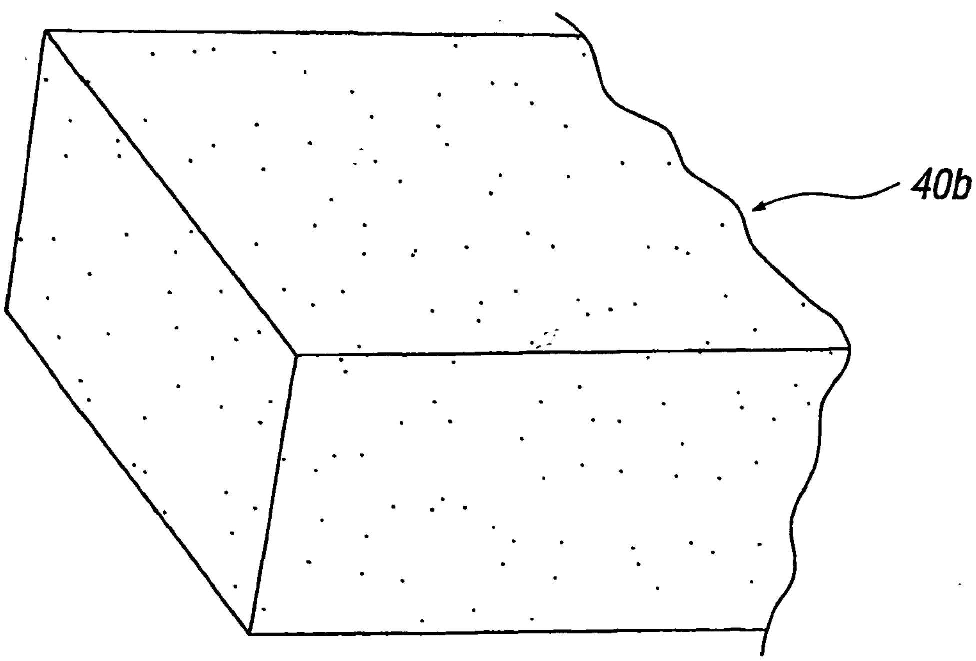

FIG. 30

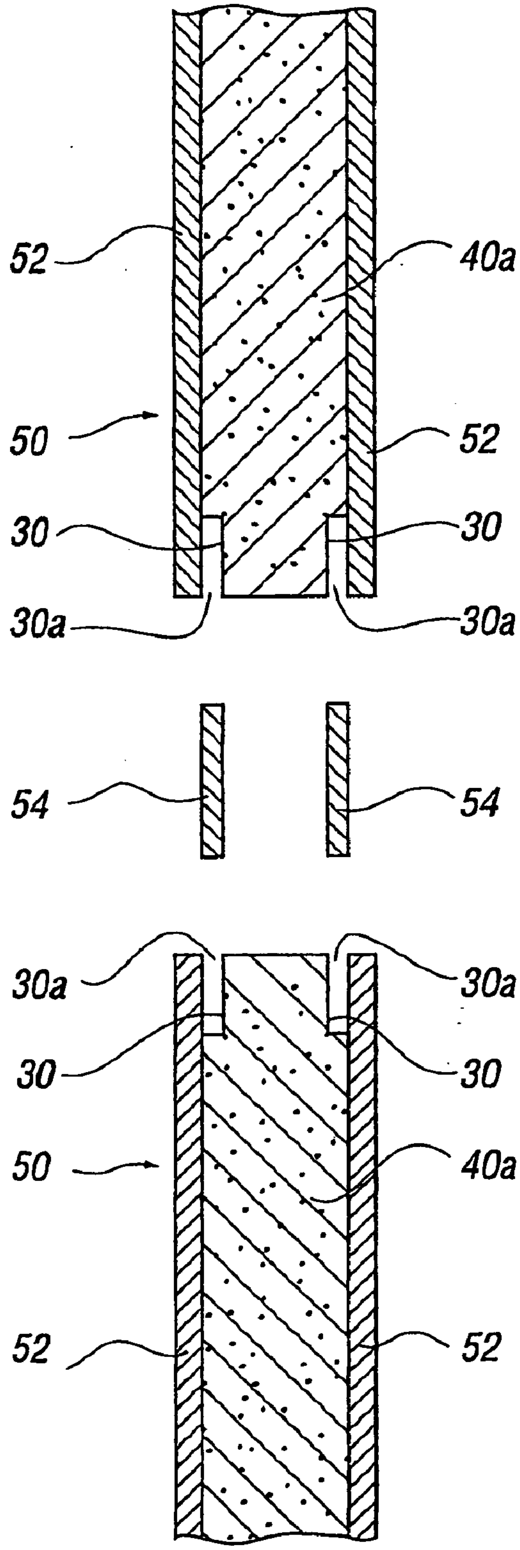
52
40a
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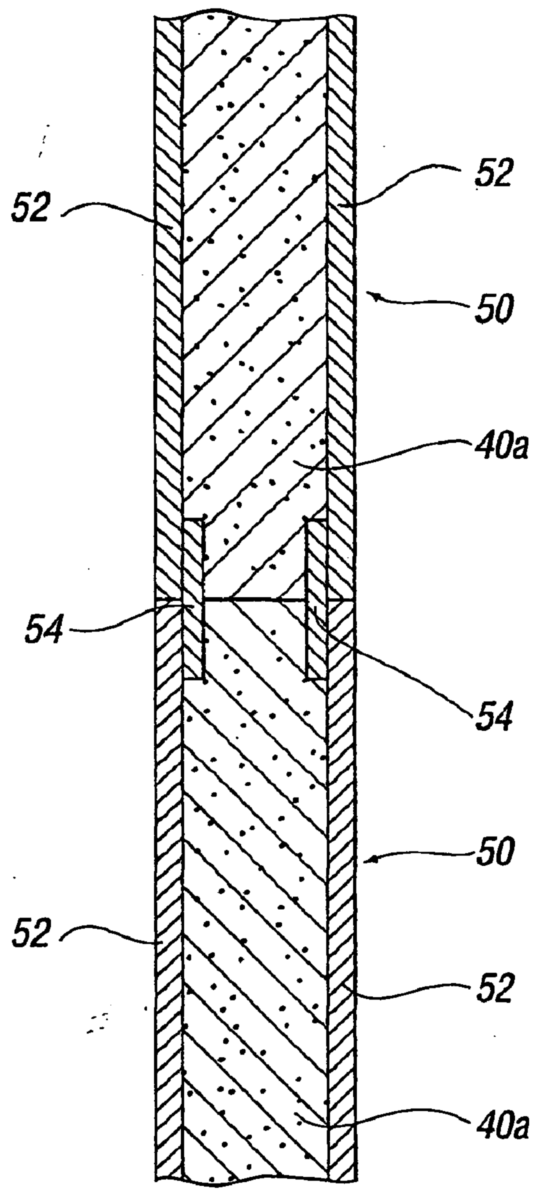
FIG. 28


52
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40a
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40a

FIG. 29

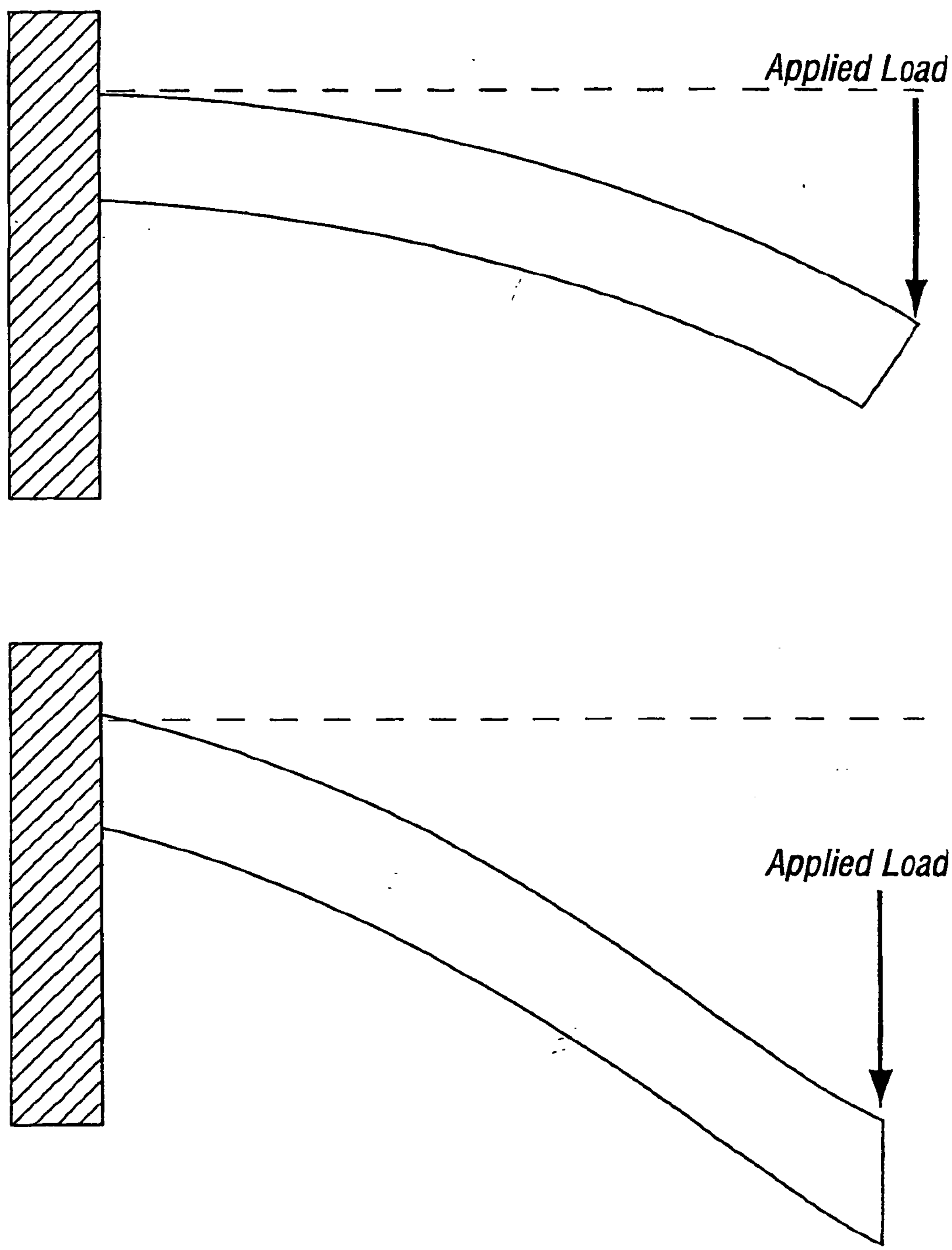

FIG. 31

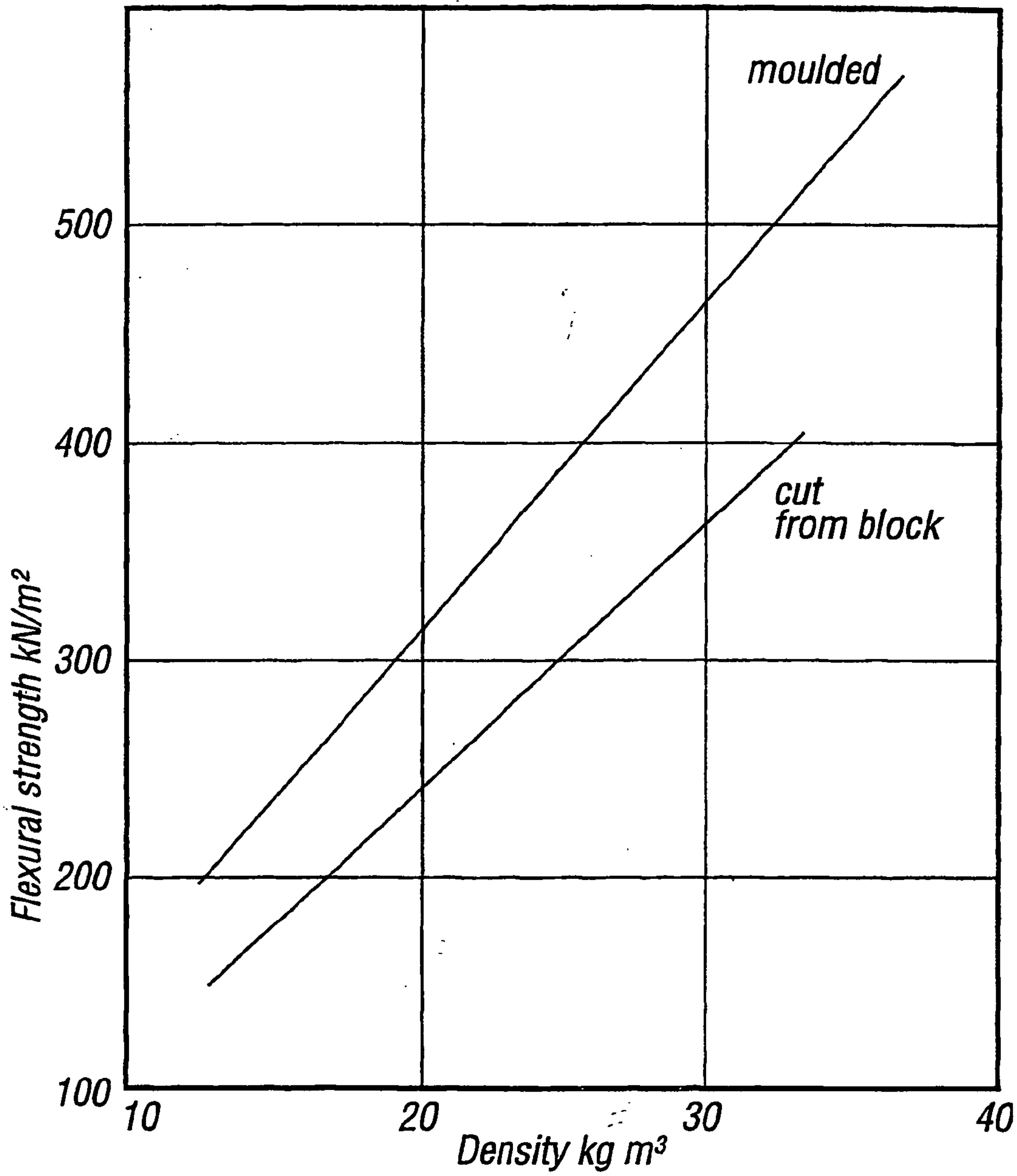
moulded
cut
from block
500
400
300
200
100
Flexural strength kN/m²
10
20
30
40
Density kg m³

FIG. 32

COMPOSITE BUILDING COMPONENTS

[0001] This invention relates to composite building components, primarily but not exclusively for use in the construction of buildings such as houses and more particularly to composite building components which are generically known as structural insulated panels or SIPs.

[0002] Typically, SIPs incorporate a relatively flat plastics foam core of rectangular shape sandwiched between, and bonded to, two relatively thin, high strength, rectangularly shaped facings to form a laminated sandwich SIPs have been in use for many years and have become well established in the construction industry, particularly in the USA, as an alternative to traditional brick/block cavity walls and the framed panel inner skin and outer skin brick/block cavity walls of timber frame buildings.

[0003] The foam cores of SIPs provide thermal and acoustic insulation which are superior to those of conventional brick or timber built houses, are resistant to moisture, shock, impact and fire and avoid the need for a water vapour barrier (house wrap). Moreover, SIPs are lightweight and easy to manipulate and a single SIP takes the place of many masonry blocks or building bricks, thereby decreasing construction time and reducing material costs. The foam cores also permit passageways or conduits for supply lines such as electrical wires to be cut in the fully formed foam cores in the factory, prior to assembly of the SIPs on site which further decreases construction time.

[0004] Instead of being applied separately in a second stage, it is advantageous to manufacture walls, floors and roofs incorporating insulation material as part of the building (or individual module structure).

[0005] Such modules or panels known as SIPs have been used in the United States for over 50 years. These SIPs vary in thickness from say 50 mm up to 300 mm and to comply with common international building component dimensions, a typical wall or floor SIP would be 2.4 metres×1.2 metres and the thickness would depend on the particular application, load bearing qualities and thermal insulation requirements.

[0006] In the USA, the most popular SIPs comprise an expanded polystyrene (EPS) core faced on its inner and outer surfaces respectively with two facing sheets of say 9 mm to 15 mm thick of OSB (oriented Strand Board) or ply wood or in some cases cementitious board. These SIP building components have been successfully used, extensively over the last 50 years in the US in the construction of houses (usually single storey). Typically, the SIPs were supported from a base length of timber fixed to a suitable foundation and joined by timber splines or so called biscuits to each other to form the walls of the building. When larger roof and wall loadings were required, the SIP modules were reinforced by incorporating a 2×4 inch timber reinforcing post within the SIP or in some cases these timber elements were used to connect the individual SIPs to each other. This method results in a SIP wall reinforced with timber frame elements.

[0007] Timber frame elements suffer from dry rot due to poor circulation of fresh air around the timber elements. The use of timber elements can also give rise to "cold spots" which reduce thermal efficiency. Therefore with any SIP for use with timber frame elements there is a need for adequate air circulation around the timber elements.

[0008] It has been ascertained that an SIP foam core has several important functions. The core has to be stiff enough to keep the distance between the facings constant and must also be so rigid in sheer that the facings do not slide over each other and to prevent buckling. If the core is weak in sheer, the facings do not co-operate and the SIP sandwich will lose its stiffness. It has also been ascertained that the foam core has to fulfil further complex demands, namely strength in different directions and low density (economics) and also has other special demands with regard to buckling, insulation, moisture absorption, ageing, resistance etc. For example, the facings are required to transmit the compressive loads down to the foundation and the adhesive used to bond the facings to the core must be sufficiently strong to resist sheer and transmit load between the core and the facings.

[0009] The most practical and economical solution initially found to manufacture an SIP giving the requisite load bearing strength and insulation qualities, was an SIP panel utilising a core of high density (HD) extruded polystyrene (XPS). Testing XPS proved that this material had the necessary qualities and the synergy required to construct an SIP panel capable of sustaining compressive loading as would be found in a typical three storey housing structure. Testing was carried out at the Building Research Establishment (BRE) and it was proven that these XPS cored SIPs faced with ply wood facings were capable of sustaining phenomenal loads.

[0010] However, further investigation showed that the initial advantages of XPS were overweighed by XPS being considerably more expensive, both in terms of manufacturing and capital expense which rendered XPS uneconomical to use in an SIP composite building component.

[0011] Further consideration was therefore made of the SIP products as manufactured and used in the USA, particularly because SIPs utilising cut EPS cores have obtained approvals (ASTM) in the USA and general acceptance for use as load bearing building panels in construction. The loading figures achievable for EPS core material in use in the USA for SIPs are common knowledge. The minimum SIP core thickness typically used for SIPS in the USA is 150 mm whereas in Europe cores of 50 mm thickness could be described as commonplace.

[0012] Cut EPS is typically in the region of three times less expensive than XPS and moulded polyurethane foam which is also used as a core in a SIP system already on the UK market. Urethane cores are dangerous in that they give off poisonous fumes when burned and so were not considered.

[0013] Also, plans are afoot globally to ban the use of urethane in composite building components because urethane used in buildings, particularly houses, is no longer considered to be an environmentally responsible material.

[0014] The beauty of using cut EPS for the core material of SIPs is that EPS is not only cheap to manufacture but is universally regarded as an environmentally responsible construction material. This is because EPS does not contain harmful fibres, represents an efficient use of natural resources which saves energy and conserves resources through its manufacture, use and disposal. EPS does not contain or release compounds harmful to the ozone layer such as CFCs or HCFC's and its manufacture and use represents no danger to health. EPS insulation, in particular, has an invaluable role to play in helping to achieve dramatic reductions in energy use and reducing emissions that contribute to the greenhouse effect EPS can be, and is being, recycled and the EPS industry is also leading the way in terms of developing a range of waste management solutions to ensure maximum recovery of waste. Further, EPS manufacture by the well known three stage process comprising pre-expansion, maturing and final block moulding is already proven and is capable of economically producing gigantic blocks of EPS of up to 20 metres long, 6 metres wide and 4 metres thick which is then cut into smaller sizes by the standard hot wire technique depending upon their intended purpose, such as cores for SIPs.

[0015] The raw material from which EPS is made is in the form of free flowing, lightweight and cellular beads made from styrene monomers derived from ethylene and benzene, themselves derived from crude oil. The beads contain an expansion agent, usually pentane, and have the appearance of granulated sugar. The raw material, which is available in various grades and can be described generally as regular and fire retardent types, is delivered in this form to the manufacturing plant in either 600 or 1000 kg 'octabins' or in a bulk carrier for transfer to storage silos, the latter being more economical.

[0016] In the first, pre-expansion, stage, the polystyrene beads are pre-expanded to 20-40 times their original volume by heating to a temperature of about 1000° C., using steam as the heat carrier, in an enclosed vessel known as a pre-expander. In pre-expansion, the volume of the polystyrene beads is increased and their bulk density changes accordingly—e.g. from 620 kg/cu. metre to 20 kg/cu. metre if the moulded density of the foamed material is to be 20 kg/cu. metre.

[0017] Following pre-expansion, the beads are cooled and dried before being stored to mature. After pre-expansion the beads have a partial vacuum and this is equalised by allowing air to diffuse through the beads. The beads are matured over around 24 hours. The density of the foamed block moulding produced from the beads is therefore practically the same because in final forming the block mould is completely filled with beads.

[0018] This second stage of maturing is required because, after cooling, the pre-expanded beads are initially still sensitive to pressure, and time must be allowed for them to acquire adequate strength. This happens by diffusion of air into the foam cells until the reduced pressure resulting from cooling and expanding agent condensation has been compensated. Accordingly, the pre-expanded beads are generally dropped straight out of the expander into a fluidised bed drier in which warm air from 25° to 35° C. is blown in through the base of the drier. Fluidised bed driers operate continuously but must be designed with sufficient length to ensure adequate drying. The residence time of the expanded beads in the fluidised bed should be 1 to 5 minutes depending on their moisture content. After drying, the freshly pre-expanded beads are transferred to a maturing silo. Whilst maturing some expanding agent (pentane) escapes and this cuts down the foam pressure decay time required in moulding.

[0019] In the third and final block moulding/secondary expansion stage, the pre-expanded and matured beads are further expanded with steam in the mould until they fuse together to form a moulded block. Although polystyrene can also be expanded with other heat sources, e.g. with boiling water, hot air and other gases, steam has decisive advantages because:—it is a highly efficient heat transfer medium; its temperature at atmospheric pressure is close to the softening point of polystyrene; it is readily available; and it helps in the actual expansion process. Polystyrene is highly permeable to steam (water vapour) and as soon as the expanding agent starts to expand the beads, steam permeates into the newly formed cells. The steam pressure inside the cells thus balances the pressure of the steam surrounding the beads which can expand against virtually no resisting force. This permits expansion of the beads to low densities.

[0020] The mould for the production of block polystyrene foam for use in producing SIP cores normally consists of two parts defining a mould cavity that produces the shape of the finished moulding with each mould part being bolted onto a steam chamber. Steam is introduced into the mould cavity through a multiplicity of special core vents or jets, usually made from aluminium alloy. The spacing and number of core vents and the total vent area is important to guarantee proper filling (with no back pressure), steaming, cooling, and consequently the quality of the mouldings. Ease of cleaning and maintenance of the core vents is an important feature for efficient operation.

[0021] The mould parts typically are closed using hydraulic pressure and the pre-expanded beads are blown into the closed mould using air injectors with the air escaping via the steam nozzles or special vents. For large block moulds, for producing gigantic EPS blocks, which are of simple design, steam is supplied via the steam chambers through the multiplicity of steam jets or vents in the mould walls. The block mould is completely filled with the matured pre-expanded beads which are, in effect closed polystyrene cells, and then steamed. As a result of the renewed heating to temperatures between 110° and 120° C., further expansion of the beads takes place but is confined to filling up the free volume of the mould cavity which compresses beads together because being contained by the mould they cannot expand freely and therefore creates internal pressure in the mould cavity. The beads fuse together along their boundary faces to form a moulded block. After a cooling (pressure reduction) period, usually using a vacuum to remove any moisture, the moulded block is dimensionally stable and can be released from the mould. Any remaining expanding agent (pentane gas) is expended during moulding so that the moulded block does not contain any residual expanding agent.

[0022] Investigations were carried out into American production methods for SIPs using EPS for the core material and the quality control procedure, and the material consistency was found to be seriously lacking and would not comply with typical current British & European quality control assurance schemes (BS5750, ESO 9000 and 9002).

[0023] Detailed testing of the lamination of SIPS using EPS faced with OSB, ply wood and cementitious board were carried out. It was found, however, that spasmodically the SIP panel would be prone to collapse in the process of manufacture, usually when the panels were placed in vacuum press for curing of the adhesive. Detailed examination of the EPS core materials showed that whilst this material was manufactured to BS 3837/BS4370 and BS4735 and the overall density of say a 2.4×12×20 cm panel showed the material was correct, if the panel was cut into segments however there was seen to be significant variations in density across the panel.

[0024] Panel samples were purchased from numerous UK EPS block manufacturers and sample weight tests showed significant variation in density from panel to panel and also segment tests showed significant density variations across individual panels. It was realised that with such density variations and poor quality control methods, EPS manufactured and as supplied in the UK market would be totally unsuitable for the manufacture of SIPs for use in housing. There was therefore a need to devise some new form of manufacturing process for the cores of SIPs that enabled the density of the finished product to be controlled so that it could be held within exacting standards.

[0025] Another disadvantage of cores cut from EPS blocks, is that judder which occurs during hot wire cutting of the EPS block causes the formation of ridges and indentations in the surfaces of the cut EPS cores. In order to provide the precise surface tolerances required for the core surfaces that are bonded to the facings, the cut cores are passed through a planar thicknesser. This process produces waste EPS, another disadvantage.

[0026] It is known that when cycle crash helmets are moulded as individual items it is possible to control the density and quality within defined limits and apply stringent quality controls, thus ensuring that this vital piece of head protection will meet the necessary British Standards tests.

[0027] The present invention involves using moulding to manufacture expanded polymer cores for SIPs as individual quality controlled items. It has been found feasible to apply quality control procedures to produce a moulded expanded polymer product capable of complying with the exacting criteria of the insulating core material of a SIP. Specifically, it has been found possible by moulding polymers in a quality controlled environment to ensure that density variations do not exceed permitted amounts.

[0028] In one aspect, the present invention resides in a structural insulated panel having a core of an expanded polystyrene moulding sandwiched between, and bonded to, two facings, facings being attached to faces of the core formed by moulding.

[0029] The core is preferably formed by expansion of polystyrene cells in a mould such that any variations in density are minimal and/or the core is of sufficiently uniform density to permit load bearing of the panel without the need for additional structural supporting elements.

[0030] Moulded cores of expanded polystyrene have been made that exhibit a density variation of as low as up to/down to ±2.0% as compared with the large density variations in cores cut from gigantic blocks.

[0031] Moulded cores in accordance with the invention are calculated to be 40% stronger than has hitherto been possible and have improved u-values.

[0032] In a still further aspect the invention resides in an individual moulding of expanded polymer for use as a core in a structural insulated panel in which the core is sandwiched between, and bonded to, two facings.

[0033] The invention also resides in methods of manufacturing any of the structural insulated panels defined above.

[0034] Hereinafter the expanded polymer will be referred to as XPS.

[0035] Significant advantages result from the invention. Firstly, the use of additional structural members of timber etc., in particular beyond the bottom story is avoided and thermal bridging within a building made form such laminated composite building components is minimised, thereby raising thermal efficiency. The structural insulated composite building components rely on the compression strength (core strength) of the component without the use of timber.

[0036] A building can be produced, in particular a house, in which not only the traditional cavity wall and brick construction are replaced but also joist and floorboard floors and timber trussed roofing systems are replaced. This is all for a fraction of the cost of these traditional systems. There are therefore significant technical advantages over other competing products, notably urethane cored composite building component structures, timber frame, and some concrete or steel framed structures.

[0037] Building costs are reduced and construction is facilitated by means of a preferred embodiment of the invention in which the basic moulded core structural insulated panel is 1.2 metres (1200 mm) wide, 0.2 metres (200 mm) thick and 2.4 metres (2400 mm) high/long and 2.88 square metres in area. It has been calculated that it takes 334 standard bricks to produce a normal cavity wall construction (one brick thick and two half brick skins) of the same area. This is clearly a major leap forward in terms of on-site productivity.

[0038] To aid in flexibility of building, there is also envisaged blocks that are 0.6 metres and 0.3 metres wide, 2.75 and 3 metres high (3 meters is storey high) and 50 mm, 75 mm, 150 mm, 250 mm and 300 mm thick.

[0039] The reinforcing facings need to be tough and to this end, facings of cementitious board, plywood, gypsum/textile composite board or OSB (oriental strand board) are preferred.

[0040] In order to ensure that the steam carries to all parts of the mould and ensure minimum variations in density, all surfaces of the mould are provided with a multiplicity, e.g. thousands, of small steam injection points.

[0041] By providing all surfaces of the mould with a multiplicity of small steam injection points, the moulded core structural insulated panel of the invention is strong, free of noxious gases, and thus is suitable for its main purpose as an environmentally responsible low cost structural building component.

[0042] Preferably, each moulded core is individually moulded in a full sized mould which provides a stronger core than that cut from a block. This is because the core has an integral surrounding skin of well-fused, denser cells.

[0043] In a preferred embodiment, which facilitates moulding and the obtaining of full thickness dimensions (at least 200 mm), as well as having other advantages, the core is made in two mirror image halves that are moulded in what is called an hermaphrodite mould so that two mould halves taken from the same mould can be bonded together to complete a two piece core.

[0044] Each mirror image half is provided with male/female location means, preferably in the form of complementary projections and recesses with each half being provided with both complimentary projections and recesses so that it is a simple matter to turn one half through 180° and engage the projections and recesses of one half with the complimentary recesses and projections of the other half.

[0045] A given strength can thus be obtained with individually moulded cores at a lower density than with cut blocks. This saving is estimated at approximately 10% for densities of 25 kg/cu.mtr. and higher. Accordingly individually moulded cores exhibit a lower density gradient than large cut blocks, especially at higher densities that always show considerable gradation in density across the thickness.

[0046] The certre of a gigantic moulded block is of significantly lower density than the overall density. It is, therefore, necessary to mould blocks at a higher density than is actually required in order to make sure that the centres of the blocks reach the required density. This problem does not occur with moulded cores and this factor gives a further saving of 8% to 10%. Since no density gradient is present, the moulded core weight and hence the product quality, are more consistent.

[0047] In order substantially to facilitate the supply of services in a building utilising moulded core structural insulated panels, preferably, the mould is provided with inserts which form hidden passageways or conduits in the ultimate moulded core which are suitable for accommodating any form of supply line but in particular electrical wires and cables. In addition to electricity, conduits may be provided for gas, communications, water, ventilation and other usages. A matrix of passageways can be formed in this way to satisfy all necessary service requirements which are aligned as between adjacent panels both side by side and one above the other. Moreover, the positions of the matrix of passageways in relation to the dimensions of the core, can be so arranged that when one panel turned onto one of its sides of lesser width to form the wall beneath a window for example, the passageways in the adjacent panels will still be in alignment.

[0048] Whilst a cut core would loose some of its strength by the removal of material for supply passageways, e.g. 0.1% this does not happen with two part moulded cores because the passageways will be lined with a skin of fused cells that is integral with the surrounding skin of fused cells.

[0049] It has been found that an organic non-solvent, moisture controlled penetrative adhesive or glue e.g. MCPU, is the most effective, not only for bonding the facings together, but also the two part core pieces when the core is moulded in two parts. Such an adhesive is stronger than the building component itself because it penetrates between the closed cells. With two piece cores, the penetration of the adhesive in this way forms a layer of adhesive which extends between the cells of each moulded piece, thereby preventing the formation of a plane of separation between the two pieces and forming a bond that lasts as long as the foam cores.

[0050] It has been ascertained that the moulded foam core and reinforcing facings glued together is comparable with an I-beam but is stronger than steel. The foam core is the equivalent of the I-beam web and the facings are the equivalents of the I-beam flanges.

[0051] Whilst the strength of the panel is more than sufficient for normal building structures, because of its composite nature it is possible to increase the strength still further by adding a layer of, for example, a textile or fibre cloth to the interior surface of one or both facings. Adding such a layer or layers may have effects other than or in addition to increasing strength depending on the properties of the material. As one example, fire retardant properties may be increased. In another example, a textile layer may have ceramics embedded in it for security reasons or a thin electricity conducting wire entwined therein which could allow for heat flow and so obviate the need to put in under floor heating. In a still further example a metal weave web or hurrican fencing could be used not only to add great strength but also to act as a security barrier giving an indication if it is cut.

[0052] In the embodiment where the core is formed in two parts, an additional layer may be provided between the core halves as well as, or in addition to, between the core and one or both facings.

[0053] Moulded expanded polystyrene cores in accordance with the invention are so remarkably strong in compression that the structural insulated panels require no further input in terms of structural elements. There are no timber beams, steelwork etc. Initial tests indicate that structural insulated panels in accordance the invention might well be approved to build up to six floors and even ten floors high without further structural elements, hence opening up a potential further market in commercial construction.

[0054] A number of other components which will be used in the building of a house. These include a ring beam, of the same basic material, which adds horizontal stability and acts as a lintel over doors and windows, a box beam for extending panel spans by adding rigidity to lengths, a corner section and a seismic joint, again made from the same basic materials.

[0055] Intermediate floors, roofs etc. may all made from these basic components in a factory environment, and the large pieces are simply assembled on site. Once assembled, the whole can then be clad in local materials (brick tiles, stone, timber, rendering etc).

[0056] The surface of moulded cores has a better appearance than that of hot swire cut cores of which the appearance has been marred due to hot wire cutting judder and this could be used to impart a quality image by moulding-in trade names or marks.

[0057] A further contribution to the good surface appearance is the fact that normally a low pentane grade material can be used which consists of smaller beads than the block moulding equivalent.

[0058] Exact dimensions are obtained since they are determined by the mould dimensions. The accuracy obtained is, therefore, much higher than in the case of block-cutting. It can be said that a design disadvantage with moulded cores is that the range of sizes offered must be limited, since mould costs are high and the mould changing time is long compared to the resetting of a hot-wire cutter. However, thickness adjustment can be easily achieved by the incorporation of spacers between the mould surfaces.

[0059] For effective insulation and structural connection, the structural insulated panels have to be provided with a system to eliminate the formation of gaps in the insulation caused by shrinkage or thermal contraction. In the case of cores cut from the block, this requires an extra, thus costly, operation by grinding, planing or milling. Moulded core panels, however, can be provided with special features, thus eliminating secondary operations to which reference will now be made. For example, recesses may be moulded in along the edges of the opposite facing surfaces of the cores by means of inserts in the mould so that the aligned recesses of adjacent cores assembled to form a wall of a building for example may receive respective elongate elements in the form of strips, known as "biscuits", for use in joining adjacent cores together without thermal bridging.

[0060] To keep the facings and the core cooperating with each other, the joints between the facings and the core must be able to transfer the shear forces between the faces and the core. The joints must be able to carry shear and tensile stresses. It's hard to specify the demands on the joints. A simple rule is that the joints should be able to take up the same shear stress as the core. The biscuit/recess joints guard against such problems occurring.

[0061] Whilst cut recesses would cause the core to lose loose some of its strength by the removal of material, the moulding process in two individually moulded part cores causes the recesses to be lined with a skin of fused cells that is integral with the surrounding skin of fused cells, like the service line passageways, to prevent any loss of strength.

[0062] Moulded two part EPS cores 200 mm wide can be produced to the requisite dimensions in a core moulding machine at a density of 24 kg per cm and a flexural strength of 400 kn/m2. To achieve the desired flexural strength using cores cut from the block, it would be necessary to use block material expanded at a minimum density of 35 kg. per cm. As previously stated, the density across the block would vary considerably and therefore it would be impossible to implement accurate quality control procedures. Accuracy of hot wire cutting would not give the dimensional tolerance required and the percentage waste ratio would climb dramatically.

[0063] The invention also comprehends methods of constructing buildings using any of the structural insulated panels defined hereinabove and to buildings constructed of such panels and/or in accordance with the method.

[0064] The advantages of moulded core structural insulated panels made according to the present invention are manifold particularly for the preferred EPS embodiment and are as follows:—

[0065] Cost effective—as compared with any other conventional building system.

[0066] Mechanical Strength—Trials on this style of construction material show it to be far superior in all performance criteria to brick, timber or concrete structures of comparable size. A finished building, e.g. a house, will also be earthquake and hurricane proof.

[0067] Workable—Using standard tools can be adapted to suit specific customer requirements.

[0068] Multi-skilled Constructors—once certification is achieved the buildings/houses can be constructed by relatively low skilled (or multi-skilled) workforce readily available.

[0069] Hidden Utilities—provision is easily made during moulding for power, communications cables, water pipes etc. to be completely hidden by engineering them directly into the moulded cores at the outset, thereby solving the conduit problems. This eliminates all types of costs relating to adding utilities after construction of the walls and is a considerable improvement on the American SIPs referred to previously in which conduits for service supply lines are cut into the already formed core which takes time and results in waste polystyrene and can cause core weakening.

[0070] Weather Strength—new, old and damaged components will meet the highest standards of resistance against wind, rain, snow, sun and frost.

[0071] Fire Resistance—of the two major constituents of the EPS moulded core structural insulated panels, one is nonflammable and has a two-hour fire rating and the other is self-extinguishing. Neither gives off toxic fumes during a fire. Thus a home can be built with out there being any combustible materials whatsoever.

[0072] Moisture Resistance—the EPS moulded core structural insulated panels are not susceptible to damage by water from blocked gutters, breached damp proof course, leaking pipes, rain exposure, etc.

[0073] Noise Attenuation—the use of high-density core material and the thickness of the walls formed from the EPS moulded core structural insulated panels components will give outstanding noise attenuation performance. Vibration through the panels is virtually impossible.

[0074] Long Life—the life of a brick and mortar house is around 100 years. Beyond that a major expense is required to keep it in good order. The design life of the EPS moulded core composite component homes will be targeted as 200 years. Information from the USA rates their SIP constructions relying on additional structural support from timber elements as having a 300-year life.

[0075] Thermal Performance—It is considered that EPS moulded core structural insulated panels will be the best thermally performing building material in the world. The u value, a measure of thermal resistance of a material, of the moulded core panel remains constant throughout the life of the component.

[0076] Readily Available Materials—all the main components of the EPS moulded core structural insulated panels will be available as commodity items or will be manufactured in-house.

[0077] Resistance to Organisms—none of the EPS moulded core structural insulated panels is prone to attack from insects, rodents, fungus or rot. If a particular problem exists in a certain part of the world, the product can readily accept fungicides, insecticides etc to resolve these issues.

[0078] Toxicity—the materials from which the EPS moulded core structural insulated panels are made contain no toxins, carcinogens or odours. EPS itself can actually be used in certain food grade applications.

[0079] Maintainability—there is no requirement for ongoing maintenance. The EPS moulded core structural insulated panels are resilient and will resist minor impact damage, e.g. from a slow moving vehicle. For serious impact damage, the building can be readily repaired using replacement panels.

[0080] Additions—the form of construction lends itself very well to extensions for additional rooms, bedrooms, garages etc. as the family grows. This fits well with many cultures where family dwellings start small and grow as funds and demands so dictate.

[0081] Technically Approved—thinner SIPs than the moulded core composite building components are well accepted in the United States. Tests that have already been carried out by BRE show that the EPS moulded core structural insulated panels exceed racking resistance requirements for both stiffness and strength given in BS5268:part 6: Section 6.1 to resist wind and vertically imposed loads in domestic buildings.

[0082] Environmentally Friendly—the materials from which the EPS moulded core structural insulated panels are made are environmentally friendly. They offer substantial energy savings; over 80% of the components (by volume) can be recycled; and 100% of each component can be used in a power plant as fuel, thereby utilising the energy expended in its production: so it is energy efficient

[0083] In order that the invention may be more fully understood, some embodiments thereof will now be described, by way of example, with reference to the accompanying drawings in which:—

[0084] **FIGS. 1 and 2** are photographs of the raw polystyrene material and pre-expanded polystyrene beads respectively used for manufacturing ESP moulded cores of a structural insulated panel made by a method illustrated in **FIGS. 3 and 4**;

[0085] **FIGS. 3 and 4** are schematic drawings illustrating one method of manufacturing a structural insulated panel (SIP) having a custom made/individually EPS moulded two part core and reinforcing facings, in accordance with one embodiment of the invention;

[0086] **FIG. 5** is a perspective view of a two part hermaphrodite mould for manufacturing EPS moulded cores of which two such cores form a two part core in the structural insulated panel made in the method of **FIGS. 3 and 4**;

[0087] **FIG. 6** is a perspective view of the lower part of the hermaphrodite mould of **FIG. 5**;

[0088] **FIGS. 7, 8** and **9** are a side elevation, bottom plan view and top plan view respectively of one EPS moulded core part made in the mould of **FIGS. 5 and 6**;

[0089] **FIG. 10** is a cross-section taken along the line A-A of **FIG. 8** of two EPS moulded core parts made in the mould of **FIGS. 5 and 6**, positioned one above the other in vertical alignment;

[0090] **FIG. 11** shows the two EPS moulded core parts of **FIG. 10** glued together to form a two part EPS moulded core:

[0091] **FIG. 12** is detail view to an enlarged scale of one part of the two part EPS moulded core of **FIG. 11**;

[0092] **FIG. 13** is a perspective view of a structural insulated panel comprising the two part EPS moulded core of **FIGS. 11 and 12** sandwiched between, and laminated by gluing to, two facings;

[0093] **FIG. 14** is a perspective view of a part of a corner structural insulated panel comprising the two part moulded core of **FIGS. 11 and 12** sandwiched between, and laminated by gluing to, four facings;

[0094] **FIGS. 15 and 16** are enlarged detail views of two adjacent structural insulated panels showing one method of joining the two panels together, for example to form a section of a wall of a building, just before and before and after joining together,

[0095] **FIG. 17** is perspective view of with parts cut away of a wall section comprising three adjacent structural insulated panels joined together in the manner shown in **FIGS. 15 and 16**;

[0096] **FIG. 18** is an exploded perspective view of a plurality of two part EPS moulded core structural insulated panels showing how the panels are joined together to form a wall of a building;

[0097] **FIG. 18***a* is diagrammatic view of the wall of a building formed of the joined together panels of **FIG. 18**;

[0098] **FIG. 19** is an exploded perspective view of a plurality of two part EPS moulded core structural insulated panels having window and door apertures and showing how the panels are joined together to form a wall of a building;

[0099] **FIG. 20** is a perspective view from the front of a building, with the front removed, to show the interior and of which the walls, floors and roof are made from two part EPS moulded core structural insulated panels according to the invention;

[0100] **FIGS. 21 and 22** are cross sectional and front elevational views respectively of a seismic joint joining together two part EPS moulded core structural insulated panels according to the invention and forming a floor and the walls of a building and which may be used to join the first floor to the walls of the building of **FIG. 20** to each other;

[0101] FIGS. **23** to **25** are part cross-sectional views of the components of a box beam using two part EPS moulded core structural insulated panels according to the invention;

[0102] **FIG. 26** is a part cross-sectional view of a box beam assembled from the components of FIGS. **23** to **25**;

[0103] **FIG. 27** is a part perspective view of a one-piece individually EPS moulded core or use in making a structural insulated panel in accordance with another embodiment of the invention;

[0104] **FIGS. 28 and 29** are enlarged detail views of two adjacent structural insulated panels using the core of **FIG. 27** showing one method of joining the two panels together for example to form a section of a wall of a building, just before and before and after joining together,

[0105] **FIG. 30** is a part perspective view of a one-piece individually EPS moulded core made of expanded polystyrene for use in making a structural insulated panel in accordance with a further embodiment of the invention; and

[0106] **FIGS. 31 and 32** show graphs.

[0107] In the drawings the same reference characters have been used to designate the same or similar parts.

[0108] Referring to FIGS. **1** to **6** of the drawings, a low pentane grade polystryrene raw material, which consists of smaller free flowing beads **1** than the block moulding equivalent from which conventional EPS cores are made, is stored in a storage container **3** shown in **FIG. 4** from whence it is subjected to the three stage process involving pre-expansion, cooling and maturing and moulding/secondary expansion.

[0109] The raw polystyrene beads **1** are fed to the first, pre-expansion, stage **5** where the beads **1** are pre-expanded to 20-40 times their original volume by heating to a temperature of about 100° C., using steam as the heat carrier in the manner previously described herein. The pre-expanded beads which are indicated by the reference **6** in **FIG. 2** are cooled and dried in a fluidised bed dryer **7** (**FIG. 4**) before being stored to mature in storage silos **8**, as what are, in effect, closed cells, again as previously described herein.

[0110] The third and final moulding/secondary expansion stage **9** (**FIG. 3**) comprises an hermaphrodite mould **10** having two mould parts **10***a* and **10***b* as will be apparent from **FIGS. 5 and 6**. The walls of the mould parts **10***a* and **10***b* define a multiplicity of nozzles or vents **12** and air injectors (not shown) for a purpose to be described.

[0111] The mould part **10***a* defines a mould cavity that is formed with a peripheral recess (not visible) which accommodates a correspondingly shaped mould insert (not shown) that projects into the mould cavity during moulding. The mould part **10***b* is formed with a grid **14** (see **FIG. 6**) of interconnecting longitudinally and transversely extending channels **16** and **18** respectively which are in alignment with respective slots **16***a* and **18***a* in the walls of the mould part **10***a* which slots and channels accommodate a correspondingly shaped grid mould insert when the mould is hydraulically or pneumatically closed to commence a moulding operation.

[0112] Additionally, the mould part **10***b* is provided with complimentary male/female locating means constituted by three projections **20** towards one end (the right hand end, as illustrated in **FIG. 6**) of the mould part **10***b* and three identically positioned complimentary recesses **22** toward the other end (the left-hand end as illustrated in **FIG. 6**) of the mould part **10***b*.

[0113] The pre-expanded and matured beads **6** are blown from the storage silos **8** into the mould cavity in the mould part **10***a* of the closed mould **10**, using air injectors (not shown) with the air escaping via the nozzles or vents **12**. Each mould part **10***a*, **10***b* is provided with its own bolted on steam chamber (not shown) which is in communication with the nozzles or vents **12** through which steam is introduced into the pre-expanded and matured bead **6** filled mould cavity in the mould part **10***a* of the closed mould **10**.

[0114] In the closed mould **10**, the beads **6** are heated to temperatures between 110° and 120° C. and are further expanded with steam which is confined to filling up the free volume of the mould cavity which compresses beads together because, being contained by the mould, they cannot expand freely. This, therefore, creates internal pressure in the mould cavity so that the beads fuse together along their boundary faces, assisted by any residual stickiness of the circumference of the individual cells due to the heating to form an individually (custom) EPS moulded shaped core part. After a cooling (pressure reduction) period, usually using a vacuum to remove any moisture, the moulded core part is dimensionally stable and can be released from the mould **10**. The moulded core part is indicated by the reference **24** and is illustrated in FIGS. **7** to **9**. Any remaining expanding agent (pentane gas) is expended during moulding so that the moulded core part **24** does not contain any residual expanding agent. The individually (custom) moulded shaped EPS core part **24** part has a surrounding skin **26**, as shown in **FIG. 12** and a grid of moulded, skin covered channels. Only the channel **18***b* is visible in **FIG. 12**.

[0115] The spacing and number of nozzles or vents **12** and the total nozzle/vent area ensures that the steam reaches all parts of the mould cavity and thus provides moulded core parts **24** of which the density is substantially uniform in that it does not vary up or down more than ±2.0%.

[0116] Referring more particularly to FIGS. **7** to **9**, the surface **28**, which is the upper surface as illustrated in **FIGS. 7 and 9** of the individually moulded core part **24**, has a peripheral recess **30** therein, i.e. a recess that extends all the way around its periphery. This peripheral recess **30** is formed by the mould insert in the recess in the mould part **10***a* and which projects into the mould cavity during moulding. A grid **14***a* of longitudinally and transversely extending channels **16***b* and **18***b* respectively are formed in the surface **32** by the mould insert grid that occupies the grid **14** of channels **16** and **18** and slots **16***a* and **16***b* during moulding. Also, it will be appreciated from **FIGS. 7 and 8** that the three projections **20** and three identically positioned complimentary recesses **22** of the mould part **10***b* are responsible for forming the three recesses **20***a* and complimentary projections **22***a* in the undersurface **32**, as illustrated, of the moulded core part **24**.

[0117] When two (mirror image) moulded core parts or halves **24** have been produced in the mould **10** and successively demoulded, they are conveyed to an adhesive coating stage **34** (**FIG. 3**) where their surfaces **32** are coated with an MCPU adhesive. Then, the two adhesive coated core parts **24** are conveyed to a pressing and setting stage **36** (**FIG. 3**) where one core part **24** is turned through 180° relative to the other core part **24** to occupy the positions shown in **FIG. 10**. In this position, the purpose of the complimentary projections **22***a* and recesses **20***a* will readily become apparent. This is because at the left hand end as illustrated, the recesses **20***a* of the upper core part **24** align with the projections **22***a* of the lower core part **24** and at the right hand end as illustrated, the projections **22***a* of the upper core part **24** align with the recesses **20***a* of the lower core part **24**. The transverse channels **18***b* of the upper and lower core parts **24** as well as the longitudinal channels (not visible) are also aligned.

[0118] Thus, when the upper and lower core parts **24** are pressed together at the pressing and setting stage **36** to adhere the one to the other as shown in **FIG. 1**. The aligned complimentary projections **22***a* and recesses **20***a* inter-engage precisely to locate the two core parts **24** with respect to each other and the aligned channels **16***b*, **18***b* form a matrix of passageways **38** for service lines. Once the adhesive has set, a two part custom moulded core **40** is produced which is conveyed to a quality check and assurance stage **42**, as shown in **FIG. 3**. The adhesive penetrates into the interstices between the closed cells of the two mould parts **24** to form a layer which is not shown in **FIG. 12** and extends between the two mould parts **24** so that there is no plane of separation between the two mould parts. Indeed the bond made by the adhesive layer is stronger than the EPS material of the moulded parts **24**.

[**0119**] The next stage which is indicated by the reference **46** in **FIG. 3** involves the application of an MCPU adhesive to one surface of each of two panel facings, e.g. of OSB, ply wood or cementious board. The adhesive coated surfaces of the facings are then conveyed to a stage **48** (**FIG. 3**) where they are applied carefully to the oppositely facing surfaces **28** of the moulded core **40**. To ensure long lasting adhesion under load bearing conditions, the moulded two part core **40** with its applied facings is conveyed to a pressing and setting/curing stage **49** (**FIGS. 3 and 4**) where a mechanically or pneumatically operated press is used. A completed structural insulated panel (SIP) **50** and which is illustrated in **FIG. 13** has a core **40** sandwiched between, and adhesively bonded to, two facings **52**.

[**0120**] **FIG. 14** shows a corner SIP **50** which, because the core **40** actually forms the corner, is virtually moisture in-penetrable as compared to conventional SIP corners formed by abutting separate SIPs against each other. It will be seen in each case that the recesses **30** are disposed inwardly of the facings which define with the core **40**, a slot **30***a* for a purpose to be described with reference to FIGS. **15** to **17**.

[**0121**] Referring to **FIG. 15**, the slots **30***a* receive strips which are called biscuits **54** which may be adhered to those parts of the core **40** and facings defining the slots **30***a* to join adjacent SIPs **50** together, as shown in **FIGS. 16 and 17**. Additionally, the abutting faces of adjacent SIPs **50** may be adhered together, optionally as shown in **FIG. 16** by forming adhesive receiving channels **56** therein so that in **FIG. 16** there is shown a longitudinally extending bead of adhesive **56***a* occupying the channels **56**. The longitudinally and transversely extending passageways **38** for supply lines can be seen in **FIG. 17**.

[**0122**] **FIG. 18** shows how SIPs **50** may be assembled to form a wall of a building which is shown completed in **FIG. 18***a*, as indicated by the reference **57** by the use of biscuits **54** in the manner shown in FIGS. **15** to **17** and by extending the facings **52** upwards beyond the cores **40** to provide top channels **60** for elongate elements **58**. It will be seen that the upper SIPs **50** have been shaped to fit with an unshown pitched roof.

[**0123**] In **FIG. 19**, apertures **62** for doors and windows are cut in SIPs **50** forming a wall **64** and are provided with respective frames **66** that fit in channels **60** formed by extending the facings **52** beyond the cores **40**. The SIPs **50** are supported on a foundation **68** by means of an elongate sole plate element **58** engaging in a channel **60** in each SIP **50**.

[**0124**] The building **70** illustrated in **FIG. 20** is a two storey (floor) building with a foundation (ground floor) **72**, walls **74**, first floor **76**, roofs **78** and a roof supporting beam **80** acting as an I-beam in which the core **40** is the equivalent of the I-beam web and the facings **52** are the equivalents of the I-beam flanges, are of SIPs **50**. The first floor **76** may be joined to the wall SIPs **50** by means of the joint **90** illustrated in **FIGS. 21 and 22** to which reference will now be made. The joint **90** comprises a channel element **91** supporting the second storey wall on the first floor **76** with a dowel element **92** extending through the channel element **91** and into the cores **40** of the SIPs **50** of the first floor and ground floor walls. The joint **90** has a capping **93** that fits over the projecting part **94** of the first floor **76**.

[**0125**] Referring to FIGS. **23** to **25**, there is shown the elements of an SIP having cores **40**, facings **52** and biscuits **54** that are adhered together into a box beam which is shown assembled and indicated by the reference **100** in **FIG. 26**. The box beam **100** is utilised for extending SIP spans by adding rigidity to lengths. An I-beam such as is mentioned in the preceding paragraph can be substituted for the box beam **100** as required by load demands.

[**0126**] The embodiment of core **40***a* shown in **FIG. 27** differs from the two part core **40** of the previous drawings in that the core **40***a* is a one-piece custom made individually moulded EPS block type core having a maximum thickness of 100 mm. As will be apparent from **FIGS. 28 and 29**, two adjacent SIP's **50** are joined together in a similar manner as described with reference to **FIGS. 15 and 16** for the SIPs **50** with the two-part cores **40** except that there are no channels **56** which receive an adhesive bead **56***a*. The core **40***a* will be made in a mould that functions in the same way as the mould **10** and the upper mould part will have a recess for receiving a complimentary mould insert to produce the recess **30**.

[**0127**] Except for the recesses for mould inserts, the simple individually moulded EPS block core **40***b* of **FIG. 30** may be made in such a mould.

[**0128**] The cores **40***a* and **40***b* are sandwiched between and bonded to unshown facings **52** to produce an SIP **50**.

[**0129**] In **FIG. 31** there are two graphs which illustrate a comparison between cores that are rigid and weak in shear respectively. In the upper graph, the trace shows that the core tested is rigid in shear, i.e. a two part moulded core **40** of substantially uniform density, and is the acceptable deflection for use in an SIP to be placed in long term compressive loading such as when used in the wall of a building.

[**0130**] On the other hand in the lower graph, the core tested is weak in shear. i.e. a core of variable (low) density such as that cut from an EPS block because the trace shows bad deflection which would be an undesirable quality for use in an SIP to be placed in long term compressive loading such as when used in the wall of a building.

[**0131**] Some typical values of flexural strength of moulded EPS cores versus those of cores cut from EPS block are set out in the graph shown in **FIG. 32** and are self evident. Core shrinkage is in the order of 0.5-0.6%, this value being obtained after two or three months.

[**0132**] Prototype testing shows representative results according to the following Table which are given purely by way of example to enable the invention to be more readily understood.

TABLE

Panel ref.	Vertical load (kN)	Panel stiffness in stiff-ness cycle, R_{stiff} (N/mm)	Panel stiffness in strength cycle, R_{str} (N/mm)	Average panel stiffness, R (N/mm)	Estimate of failure load, $F_{max,ext}$ (kN)	Failure load, F_{max} (kN)
Test series 1						
MPR1	0	4613	5101	4857	25	33.59
MPR2	0	5010	5063	5023	32	47.54
MPR3	0	4294	5418	4856	42	39.54
MPR4	0	2951	4986	3968	40	34.44
MPR5	0	4225	5677	4951	40	38.80
MPR8	5	6558	7136	6847	60	45.02
MPR7	5	6987	6983	6975	48	44.78
MPR8	5	5058	5821	5439	44	54.02
MPR9	5	5861	7176	6519	46	49.28
MPR10	5	5521	7627	6574	48	48.03
Test series 2						
MIP1	0	3543	3894	3718	36	26.46
MIP2	0	642	877	759	10	5.70
MIP3	0	392	553	472	8	6.00

[0133] Various modifications may be made to the embodiments described without departing from the inventive concepts defined in the introductory portion of this specification. For example, the EPS moulded cores may be cut to smaller sizes of rectangular shape or different shapes depending upon their location and/or application (see **FIG. 18** for example) either before or after bonding of the facings **52**. In such instances, it may be necessary, depending upon load requirements, to provide the cut surface of an EPS moulded core with a facing such as a biscuit to restore any losses in strength that might conceivably occur.

1. A structural insulated panel having a core of expanded polystyrene sandwiched between, and bonded to, two facings, the facings being attached to faces of the core formed by moulding.

2. A panel as claimed in claim 1 wherein the core is an expanded polystyrene moulding.

3. A panel as claimed in claim 2 wherein the core is formed by expansion of polystyrene cells in a mould in such that any variations in density are minimal.

4. A panel as claimed in any preceding claim wherein the expanded polystyrene is produced by pre-expanding polystyrene, maturing the pre-expanded polystyrene and then expanding the pre-expanded polystyrene and then expanding the pre-expanded matured polystyrene in steam.

5. A panel as claimed in any preceding claim wherein the panel dimensions are 1.2 metres wide, 0.2 metres thick and 2.4 metres high/long.

6. A panel as claimed in any preceding claim wherein the facings are made from cementitious board, plywood, gypsum/textile composite board or OGB.

7. A panel as claimed in any preceding claim wherein the core comprises two mirror image halves.

8. A panel as claimed in claim 7 wherein each mirror image half of the core is provided with male/female location means for engagement of the two halves.

9. A panel as claimed in any preceding claim wherein the core includes at least one passageway.

10. A panel as claimed in claim 9 wherein there is a matrix of passageways positioned such that each passageway will align with, and be capable of connection to, a passageway of an adjacent such panel.

11. A panel as claimed in any preceding claim wherein an organic non-solvent, moisture controlled penetrative adhesive or glue is employed for bonding the parts of the panel together.

12. A panel as claimed in any preceding claim including recesses along the edges of oppositely facing surfaces of the core for receiving joining elements for connecting the panel to another such panel.

13. Use of an individual moulding of expanded polystyrene as a core in a structural insulated panel in which the core is sandwiched between, and bonded to, two facings.

14. A method of manufacturing a structural insulated panel comprising forming an expanded polystyrene core with at least two opposite faces produced by moulding and bonding facings to the two moulded faces.

15. A method as claimed in any preceding claim wherein the step of forming an expanded polystyrene core comprises pre-expanding polystyrene beads by heating the beads and providing steam thereto, cooling and drying the pre-expanded beads, maturing the pre-expanded beads and then further expanding the pre-expanded and matured beads with steam in a mould.

16. A method as claimed in claim 15 wherein the mould used for further expansion of the pre-expanded and matured beads comprises a two part mould defining a mould cavity, each part being connected to a steam source, wherein the surfaces of the mould cavity are provided with a multiplicity of steam injection points.

17. A method as claimed in either claim 15 or claim 16 wherein the mould is an hermaphrodite mould.

18. A method as claimed in claim 17 wherein the mould is shaped to provide each half of the core with male/female location means.

19. A method as claimed in any one of claims 15 to 18 wherein the mould is shaped to form recesses along the edges of oppositely facing surfaces of the core.

20. A method as claimed in any one of claims 15 to 19 wherein the mould is shaped to form at least one passageway in the core.

21. A method as claimed in any one of claims 14 to 20 wherein the bonding of parts of the panel is carried out with an organic non-solvent, moisture controlled penetrative adhesive or glue.

22. A method of constructing a building comprising using a panel as claimed in any one of claims 1 to 12.

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