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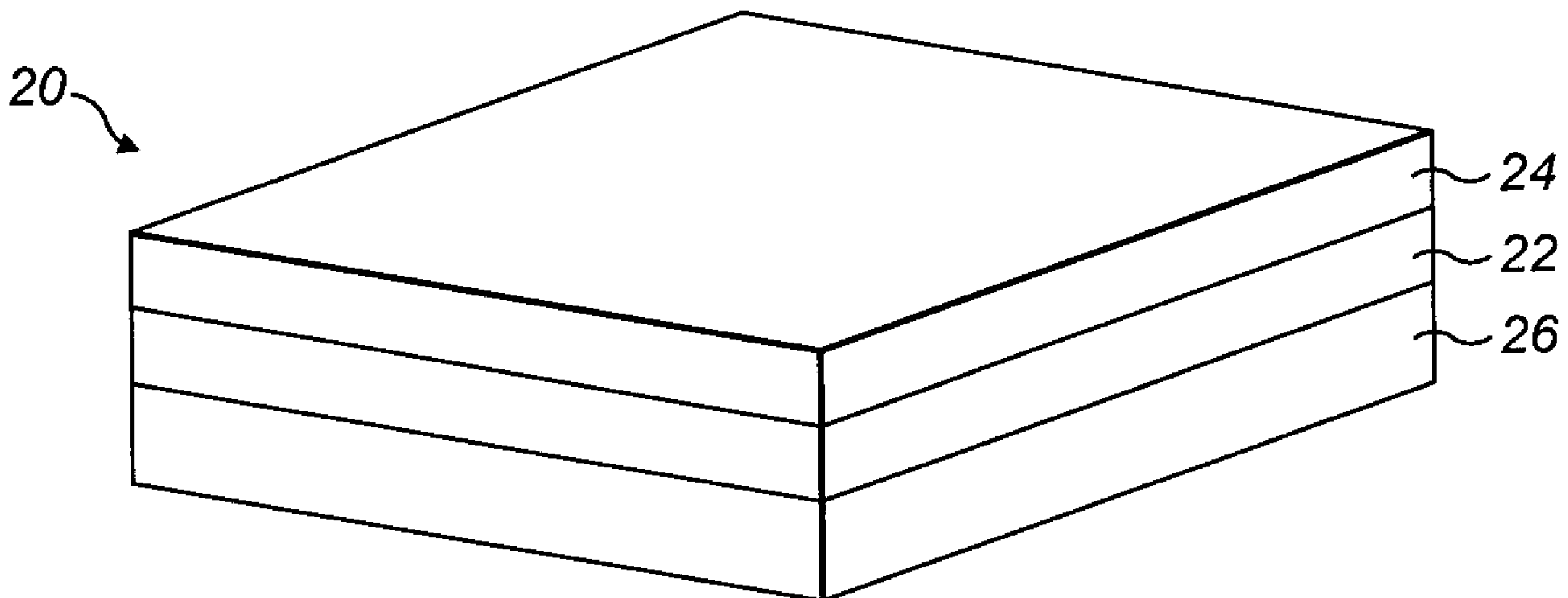
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(54) **Titre : PANNEAUX INTERIEURS AMELIORES D'AERONEF VERTS**

(54) **Title: IMPROVED, GREEN AIRCRAFT INTERIOR PANELS**



(57) **Abrégé/Abstract:**

The present invention relates to sandwich panels used as aircraft interior parts. In addition to provide a finishing function, the sandwich panels need to have certain mechanical properties and have sufficient fire resistance to retard the spread of fire within the vehicle interior. The present invention provides an aircraft interior panel with skins comprising natural fibre reinforced composites based either on an inorganic thermoset resin or a thermoplastic resin. Such panels provide the required flame and heat resistance, allow easy recycling and disposal, are cheaper and offer significant weight savings over conventional sandwich panels.

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ABSTRACT**IMPROVED, GREEN AIRCRAFT INTERIOR PANELS**

5 The present invention relates to sandwich panels used as aircraft interior parts. In addition to provide a finishing function, the sandwich panels need to have certain mechanical properties and have sufficient fire resistance to retard the spread of fire within the vehicle interior. The present invention provides an aircraft interior panel with skins comprising natural fibre reinforced composites
10 based either on an inorganic thermoset resin or a thermoplastic resin. Such panels provide the required flame and heat resistance, allow easy recycling and disposal, are cheaper and offer significant weight savings over conventional sandwich panels.

IMPROVED, GREEN AIRCRAFT INTERIOR PANELS

Field of the Invention

5 The present invention relates to aircraft interior panels comprising a sandwich panel structure. The aircraft interior panels may be used in applications like floors, ceilings, sidewalls and stowage bins.

Background to the Invention

10 Sandwich panels are used in many aircraft interior applications, such as floors, sidewalls, ceilings and stowage compartments. These types of sandwich panels may be used in similar applications in other types of transport vehicles. In addition to providing a finishing function, the sandwich panels need to have certain mechanical properties and have sufficient fire resistance to retard the spread of fire within the vehicle interior.

15 Of particular interest to the applicant is the use of sandwich panels in aircraft interiors. Consequently, the following description focuses on the application of novel "green", or environmentally friendly, sandwich panels in aircraft interiors. It will be abundantly clear that the present invention may extend to sandwich panels in general having the composition of the aircraft interior panels described herein. Such general sandwich panels enjoy far greater applicability than just aircraft interiors and would not require any modification.

20 Current aircraft interior panels are sandwich structures comprising a core sandwiched between outer skins. The materials used in these panels are chosen primarily for their fire resistant properties. For commercial airlines, there are strict regulations governing the fire resistant properties of the materials used in the cabin, along with limits as to the heat and smoke released during combustion of such materials. This has led to the widespread use of glass fibre-reinforced composites based on phenolic resins in conventional aircraft interior parts. In addition to their appropriate fire resistance, the panels based on these composite materials may be moulded into complex shapes, they have a high strength-to-weight ratio, have low maintenance costs and are generally easily installed.

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In general, phenolic resins and glass fibre pre-pregs comprise outer skins of such panels. Alternatively, skins may be made from a composite of glass fibre with epoxy or carbon fibre with epoxy. All these skin materials have known limitations. Phenolic resins are regarded as highly noxious and can cause skin problems, such as dermatitis. Glass fibres cause irritation of the skin, eyes and upper respiratory system producing skin eruption similar in appearance to poison ivy, pneumoconiosis and silicosis. If ingested, glass fibres can also cause gastrointestinal conditions.

The core of a conventional panel is usually formed from a Nomex® (RTM) honeycomb that contains aramide fibres. These fibres are a heat-resistant synthetic fibre, but have a known disadvantage in that upon fracturing, they produce small fibrils that are harmful to the lungs and cause skin irritation.

The use of such noxious skin and core materials presents difficulties during manufacturing, while heating the resins and where fibres may be exposed after curing, such that careful handling is required. Personal protective equipment is therefore required during manufacturing such panels. This does not apply once the part is made and installed on the aircraft. However, more significant issues arise at the end of the service life of the aircraft where it is scrapped and parts are disposed of. This is of course true for removal and disposal of interior panels at any stage of the aircraft's life, for example during a refit or conversion process. Moreover, the noxious nature of the materials makes the panels poor candidates for recycling and so often end up being sent for burial at landfill. They do not leach but still constitute harmful residues. This is contrary to the aerospace industries current drive for products that achieve a better environmental performance.

The ideal situation would therefore be that in which the sandwich panels are more environmentally friendly while maintaining an excellent technical performance. For example, sandwich panels that are easier to recycle would be extremely advantageous.

Summary

Against this background and from a first aspect, the disclosure describes an aircraft interior panel comprising a core sandwiched between first and second skins, wherein the first and second skins both comprise natural fibres and a resin.

5 The natural fibres may be a natural fibre fabric. The first and second skins may comprise outer skins.

The use of natural fibres provides significant “green” benefits in terms of ease of recycling and disposal, and also offers other advantages such as reduced weight and lower cost as will be described in more detail below.

10 In order to improve the performance of the sandwich panel in the event of a fire, the natural fibres may be treated with a flame retardant prior to them being formed into the skins. A non-halogenated fire retardant may be used, such as a boron derivative, e.g., disodium octaborate tetrahydrate ($\text{Na}_2\text{B}_8\text{O}_{13} \cdot 4\text{H}_2\text{O}$). Phosphate nano-particles and/or nano-graphene may also be used as a fire
15 retardant to coat the fibres.

Although many types of natural fibres may be used, flax is currently one of the preferred choices.

Optionally, the resin is an inorganic thermoset resin, for example an aluminium silicate derivative such as a (potassium, calcium) –poly(sialate-siloxo)of the -Si-O-Al-O-Si-O- type, with different Si:Al atomic ratio in the
20 poly(sialate) structure. The resin may comprise components such as any, and any combination of, a hardener and an anti-shrinkage additive. Suitable choices for the hardener include aluminium and copper phosphate mixtures, and suitable choices for the anti-shrinkage additive include an aluminium silicate derived
25 compound and hollow glass micro-spheres.

The resin may also be a thermoplastic resin such as a polypropylene resin or a polylactic acid resin. The resin may be used in a matrix further comprising a fire retardant. Suitable choices for the fire retardant in a polypropylene resin matrix include ammonium polyphosphate optionally as nano-particles, and nano-
30 graphene. Suitable choices for the fire retardant in a polylactic acid resin matrix include ammonium polyphosphate, optionally as nano-particles, zinc borate and nano-graphene.

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The aircraft interior panel may comprise a flame retardant protective coating on an outer surface of at least one of the first and second skins. Optionally, a protective coating comprising sodium silicate nano-particles encapsulated in aluminium nano-particles is provided on the first skin and/or the
5 second skin when formed from polypropylene resin. Optionally, a protective coating comprising nano-particles of phosphates, ammonium salts, nanographene, carbonate, sodium silicate and acrylic resin is provided on the first skin and/or the second skin when formed from polylactic acid resin.

Optionally, the core may comprise balsa wood, with or without fire
10 resistance. Balsa wood is a natural product that is extremely easy to handle in terms of disposal and recycling. The core may contain a paper honeycomb. The core may comprise a thermoplastic foam. In some embodiments, the core comprises combinations of balsa wood, paper honeycomb and a thermoplastic foam. Where a thermoplastic foam is present, it is preferably fire resistant, like a
15 polyvinylidene fluoride (PVDF) foam, a Polyetherimide-based (PEI) foam or others. An advantage of using a foam over the conventional honeycomb structure might be enhanced soundproofing. When used in aircraft interiors, this might provide a quieter, more pleasant environment for passengers.

The core and/or skins may have been treated to improve adhesion, for
20 example adhesion between the core and skins or between the skins and protective coating. For example, the core and/or skins may have been subjected to a dielectric barrier discharge treatment to activate one or more surfaces for improved adhesion. For example, atmospheric pressure air dielectric barrier discharge, or other surface activation mechanisms, may be used for this purpose.
25 Optionally, chemical etching may be used to treat the core and/or skins for enhanced adhesion.

For certain applications, aircraft interior panels may comprise more than three layers. For example, in addition to the core, first skin and second skin, the aircraft interior panel may comprise further skins or further cores, or both further
30 skins and cores, or other layers. Other layers may include conventional finishes for decorative purposes or fire retardant coatings. The core may be sandwiched between the first and second skins in all configurations, with first and second

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skins being arranged outermost in the aircraft interior panel, i.e., the first and second skins provide the outer surfaces of the aircraft interior panel.

The aircraft interior panels described above avoid the use of noxious materials. Put another way, the aircraft interior panels may comprise only natural materials or the aircraft interior panels may not comprise noxious materials. As a result, handling during manufacturing, recycling or disposal of the aircraft interior panels is much easier and cheaper. For example, when present in an aircraft that has reached the end of its service life, the green aircraft interior panels may be removed and recycled or disposed without stringent requirements for protecting those working on the aircraft due to the absence of noxious materials that would require special handling.

Importantly, the aircraft interior panels as constructed above may achieve or even exceed the mechanical and fire resistance properties of conventional aircraft interior panels without incurring any weight penalty. For example, aircraft interior panels constructed as described above pass the Ohio State University (OSU) test according to FAA and EASA requirements with lower or similar heat release rate values than the conventional sandwich panels. Furthermore, the aircraft interior panels provide the required low levels of heat and smoke production upon combustion. Their performance complies with, and may even exceed, the certification requirements imposed on civil airliners.

A further advantage of aircraft interior panels as described herein is that conventional manufacturing processes may be used in their construction, and hence conversion costs may be avoided.

Also, natural fibres are typically **45%** to **80%** cheaper than glass fibres.

In addition to the above, there is a further significant benefit to be gained from aircraft interior panels as described herein. This is because the green aircraft interior panels are generally much lighter than conventional panels. For example, an aircraft interior panel as described herein of the same size and configuration as a conventional panel will weigh far less. This weight saving is gained mostly from the use of natural fibres instead of glass fibres: glass fibres have a typical density of $\sim 2.6 \text{ g/cm}^3$, whereas flax fibres have a typical density of $\sim 1.5 \text{ g/cm}^3$. This advantage is particularly significant in commercial airliners

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where the overall interiors weight could be reduced by **15%-30%** when using the thermoplastic and the inorganic resin-based panels, respectively.. Weight reduction in aircraft is always a high priority, particularly for airlines. This is because the reduced weight leads to a reduced fuel consumption. This provides important cost savings to the airlines in reduced fuel costs, and also brings significant environmental advantages with the reduction in CO₂ emissions.

It has been estimated that each kg of weight reduction in a typical commercial airliner provides a reduction of **0.02 kg** to **0.04 kg** of fuel burn per hour. Assuming a typical life of **100,000** hours for an airliner, then for every single kilogram of weight saved, a fuel burn reduction of **4 tonnes** and a reduction in CO₂ emissions of **12.5 tonnes** is achieved over the working life of the airliner. A typical airliner that uses aircraft interior panels as described herein for a typical arrangement of ceilings, floors, sidewalls, bulkheads, stowage compartments and other parts in the cabin could see a weight reduction of **200** to **500 kg** for panels made of the inorganic resin and **100 kg** to **250 kg** for the panels made of the thermoplastic resin. The weight reduction also equates to **2,500** to **6,500 tonnes** reduction in CO₂ emissions during the lifetime of the airliner for panels made of the inorganic resin and **1,300** to **3,250 tonnes** reduction in CO₂ emissions during the lifetime of the airliner for panels made of the thermoplastic resin. . Moreover, further CO₂ savings could be achieved at end of the service life due to easier recycling and disposal of the sandwich panels.

In addition, for the particular case of the thermoplastic resins, the energy to produce a kg of polylactic acid is **40 MJ** and **77 MJ** for polypropylene. This is to be compared with **139 MJ/kg** of a phenolic resin or **140 MJ/kg** of epoxy resin. This means energy savings in between **5,000** and **20,000 GJ** per year if all the epoxy-based panels are replaced by thermoplastic-based ones. On the other hand, life-cycle impact studies show that natural fibers in a composite panel give a **66%** reduction in the environmental impact compared to glass fibers (the energy to manufacture natural fibers represents only one third or less of that of glass fibres). If the panel contains **40%** of natural fibers instead of glass fibres, energy savings in between **900** and **2,000 GJ** per year can be achieved.

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Additional environmental benefits, such as reduced particle and gas emissions, can be achieved due to the lower environmental impact during the production of natural fibres and thermoplastic matrices compared to the glass fibre reinforced thermoset composites.

5 Therefore, the replacement of epoxy-based composites by thermoplastic composites will avoid the generation of huge amounts of hazardous waste from aircraft interiors that currently may only be disposed by incineration, generating CO₂ emissions, or by landfill. The latest panels do not really eliminate the waste due to the lack of degradability of these materials, but increase the amount of
10 noxious substances released to the environment. However the thermoplastics panel can be recycled and used for several further applications such as pallets, wood plastic applications, insulating elements, etc.

The disclosure also describes an aircraft including any of the aircraft interior panels described above.

15 The disclosure also describes a method of manufacturing any of the aircraft interior panels described above, comprising curing a stack of the natural fibre fabrics, the resin and the core to form the aircraft interior panel.

The aircraft interior panel may be formed in a single step, in two steps or in more than two steps. For example, the first and second skins may first be
20 formed, and then joined to the core in a second step. As such, the method may comprise laying up the natural fibre fabrics, impregnating the fabrics with the resin, curing the skins, laying up the core between the skins to form a stack, and curing the stack to form the aircraft interior panel. Alternatively, in a one-step process, the method may comprise laying up the natural fibre fabrics on the core,
25 adding the resin to form the stack, and curing the stack in one step to form the aircraft interior panel. Any of the above curing steps may be performed using a vacuum bag process. For example, the vacuum bag process may comprise curing for **30** min to **24** hours without vacuum pumping to prevent the elimination of water during the polymerization of the inorganic thermoset resin. This may be
30 performed at a temperature range of **25-80** degrees Centigrade. Pressure may be applied (using the atmospheric pressure, by a mechanical press or with an

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autoclave) to compact the assembly. These steps may be followed by curing the inorganic thermoset at room temperature with vacuum pumping until constant weight is achieved. This final step has been found to remove the water once the inorganic thermoset resin has polymerized. While these steps are preferred for
5 manufacture using an inorganic thermoset resin, they may also be used when employing a thermoplastic resin. An additional step of adding a protective coating may be included.

The precursors of the resin may include any of and any combination of: a hardener, and an anti-shrinkage additive. The resin may include an aluminium
10 silicate derivative, optionally with different Al:Si ratios. The anti-shrinkage additive may include an alumino-silicate derived compound or hollow glass microspheres or others. The resin might also be a thermoplastic resin such as a polypropylene resin or a polylactic acid resin. The manufacturing process for the thermoplastic-based panels is detailed later on.

15 The method may further comprise immersing the natural fibre fabrics in a flame retardant solution. This step may be performed prior to reinforcing the resin with the natural fibre fabrics. The flame retardant may be a boron derivative. The natural fibres may be immersed in a solution of flame retardant at
25 to 80 degrees Centigrade for 20 to 80 minutes, and then dried at room
20 temperature. Fire retardants may be added to the resin.

Optionally, the method may further comprise adding an adhesive between the skins and the core, or treating the core to activate its surface to improve adhesion of the core to the skins. For example, one or more surfaces of the core may be activated using the following method or using any other surface activation
25 treatment. The method may comprise treating the core using a dielectric barrier discharge. This may be done by placing the core on a platen between electrodes and applying an alternating high voltage current. The skins may be treated to improve adhesion of a fire retardant protective coating, for example using chemical etching.

30 When using the thermoplastic resin to build up the panels, the equipment and processes are also compatible with those used for manufacturing conventional interior parts. The panel's outer skins may be produced previously

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using a standard compounding setup for thermoplastic sheets production (e.g., **200°C/1 min** for the polypropylene sheets, and **140°C/1 min** for the polylactic acid based panels). The thermoplastic sheets, the natural fibres, the adhesives and the core may then be sandwiched using a hot-plate press (e.g., **100°C/1 min** and the applied force may be **87KN** for both types of panels), following a process similar to the crush core manufacturing method currently used for interior parts production. The outermost skin may include the flame retardant coating that may be applied using conventional painting equipment. Additional finishing layers may be applied following the same processes as those employed currently for the production of conventional panels. Advantageously, no additional investment is needed to produce the novel green panels, rather than the existing facilities for manufacturing conventional panels.

For the thermoplastic-based panel assembly, the skins may be bonded to the sandwich core using a fire resistant polyurethane-based adhesive. The polyurethane-based adhesives have been found to be the most convenient solution for the configurations tested, but are not the only option to bond the skins and the core. Alternative formulations and adhesive types such as epoxy-based adhesives may be used depending on the final properties required for the application.

The core of the sandwich panels may be either a fireproof paper honeycomb, balsa wood or a fire resistant thermoplastic foam. The type of core used may be selected according to the properties required for the aircraft interior panel. The panels tested with these cores have shown good results in terms of fire resistance.

Regarding the protective coating, once the panel is assembled, the final protective coating may be applied on a skin, preferably the outermost skin. This protective coating increases the fire resistance of the aircraft interior panels, acting as a barrier against fire. The compositions of this coating may be selected according to the type of skin being used, and may vary between panels based on polypropylene and polylactic acid.

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As a first step prior to applying the protective coating, the skin's surface may be activated by chemical etching. This process allows optimizing the adherence of the protective coating to the surface.

5 The protective coating developed for the polypropylene-based panels may comprise sodium silicate nano-particles encapsulated with alumina nanoparticles (10%). The protective coating may be applied by manual impregnation of the surface of the skin with a solution of the nano-particles. A first layer may be applied on the surface and dried in an oven for 10 minutes at 40°C. Then a second layer (in the same side and so, same outer skin) may be applied and
10 dried again in the oven for 30 min at 40°C.

The protective coating developed for the polylactic acid-based panels may be made of nano-particles of phosphates, ammonium salts, nanographene, carbonate, and sodium silicate. Additionally, a small quantity of acrylic resin may be added to the mixture of nano-particles to improve the flexibility, the adherence
15 and thermal stability of the coating. The coating may be manually applied to the skin of the aircraft interior panel in a similar way to the method used for the polypropylene based panels.

The disclosure describes an aircraft interior panel including a core sandwiched between first and second skins. The first and second skins both
20 include a composite including a composite matrix of flax fibres set within a resin and the flax fibres are pretreated with a non-halogenated flame retardant prior to being set in the resin. The flame retardant is of a concentration sufficient to limit a heat release of the panel to a maximum heat release rate of less than $65 \text{ kW}\cdot\text{m}^{-2}$ and a total heat release during the first 2 minutes of less than $65 \text{ kW}\cdot\text{m}^{-2}$ and a
25 total heat release during the first 2 minutes of less than $65 \text{ kW}\cdot\text{min}\cdot\text{m}^{-2}$ when exposed to $3.5 \text{ W}\cdot\text{cm}^{-2}$ heat flux.

The flame retardant may include disodium octaborate tetrahydrate.

The resin may be an inorganic thermoset resin.

The inorganic thermoset resin may include an aluminium silicate
30 derivative.

The resin may include a thermoplastic resin.

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The aircraft interior panel may include a flame retardant protective coating on an outer surface of at least one of the first and second skins.

5 The resin may include polypropylene and the protective coating may include sodium silicate nanoparticles encapsulated within aluminium nanoparticles.

The resin may include polylactic acid and the protective coating may include nano-particles of at least one of phosphates, ammonium salts, nanographene, carbonate and sodium silicate.

10 The thermoplastic resin may include at least one of polypropylene and polylactic acid.

The core may include one of a paper honeycomb and a thermoplastic foam.

The thermoplastic foam may include a polyvinylidene fluoride foam.

15 The core may have been activated to enhance adhesion to the first and second skins.

The core may be activated by one of a dielectric barrier discharge process, chemical etching, and an adhesive.

The disclosure describes an aircraft including one or more aircraft interior panels according to any of the above.

20 The disclosure describes a method of manufacturing an aircraft interior panel as described above. The method may involve pretreating the flax fibers by immersing the flax fibres in the non-halogenated flame retardant and curing a stack of the pretreated flax fibres, the resin and the core so as to form the aircraft interior panel.

25 The method may further involve laying up the flax fibres, impregnating the flax fibres with the resin, curing the flax fibres and resin to form the first and second skins, laying up the first and second skins on each side of the core to form a stack, and curing the stack to form the aircraft interior panel.

30 Laying up the flax fibres may involve laying up flax fibre fabrics impregnated with the resin on both sides of the core to form the stack, and curing the stack may involve curing the stack in one step to form the aircraft interior panel.

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Curing may involve a vacuum bag process, a mechanical press or an autoclave.

The method may involve providing a flame retardant protective coating on an outer surface of at least one of the first and second skin.

5 The method may involve activating the surface of the core or using adhesives to improve adhesion of the core to the first and second skins.

Brief Description of the Drawings

10 Preferred embodiments will now be described, by way of example only, with reference to the following drawings in which:

Figure 1 is a perspective view of an aircraft interior panel according to the prior art;

Figure 2 is a perspective view of a green aircraft interior panel according to a first embodiment of the current invention;

15 Figure 3 is a perspective view of a green aircraft interior panel according to a second embodiment of the present invention;

Figure 4 is a schematic representation of a method of assembling a green aircraft interior panel according to a first embodiment of the method of the present invention;

20 Figure 5 is a schematic representation of a method of assembling a green aircraft interior panel according to a second embodiment of the method of the present invention;

25 Figure 6 is a schematic representation of a method of assembling a green aircraft interior panel according to a third embodiment of the method of the present invention;

Figure 7 is a schematic representation of a method of assembling a green aircraft interior panel according to a fourth embodiment of the method of the present invention;

30 Figure 8 is a perspective view of a green aircraft interior panel according to a third embodiment of the current invention;

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Figure 9 is a perspective view of a green aircraft interior panel according to a fourth embodiment of the present invention;

Figure 10 is a schematic representation of a method of assembling a green aircraft interior panel according to a fifth embodiment of the method of the present invention;

Figure 11 is a schematic representation of a method of assembling a green aircraft interior panel according to a sixth embodiment of the method of the present invention;

Figure 12 is a table showing tests performed on the inorganic thermoset resin-based skins;

Figure 13 is a graph showing tests performed on the inorganic thermoset resin-based skins of Figure 12;

Figure 14 is a table showing tests performed on inorganic thermoset resin-based aircraft interior panels; and

Figure 15 is a graph showing tests performed on the inorganic thermoset resin-based aircraft interior panels of Figure 14.

Detailed Description of the Invention

According to the prior art, an aircraft interior panel 10 comprises three layers, as shown in Figure 1. The middle layer is a core 12 made of a Nomex® (RTM) honeycomb structure. The core 12 is sandwiched between an upper skin

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14 and a lower skin **16**. Both upper and lower skins **14, 16** comprise a phenolic resin and glass fibre pre-preg. The skin layers **14, 16** are bonded to the core **12** using the phenolic resin present in the pre-preg, which acts as an adhesive.

5 Figure **2** shows a green aircraft interior panel **20** according to a first embodiment of the present invention. The green aircraft interior panel **20** comprises a core **22** sandwiched between an upper skin **24** and a lower skin **26**. In contrast to the aircraft interior panel **10** of Figure **1**, the materials used in the panel **20** of Figure **2** are environmentally friendly.

10 The core **22** is a PVDF foam, typically a few mm thick. In alternative embodiments, the core **22** may comprise balsa wood or a paper honeycomb. Joined to the core **22** are the corresponding upper and lower outer skins **24, 26**. Each skin **24, 26** comprises a natural composite material made from natural fibres set within resin, an inorganic thermoset resin in this embodiment. Embodiments using thermoplastic resins are described later. In this embodiment,
15 there is only one layer of flax fibres that is impregnated with an aluminium silicate derivative resin. The inorganic thermoset resin has excellent heat resistant properties and can withstand temperatures of up to **1000** degrees Centigrade. The heat resistance of natural fibres does not tend to be as good, so they may be treated with a flame retardant, as will be described in more detail with respect to
20 some of the methods of manufacture according to the present invention (see, for example, Figure **5** and the corresponding description).

The present invention is not limited to aircraft interior panel structures comprising only three layers. More than a single core layer may be included, and more than a single skin layer may be included to any one side of the core.

25 An example of a further green aircraft interior panel **30** is shown in Figure **3**. The aircraft interior panel **30** comprises five layers that are stacked as follows, from top to bottom: an outer upper skin **34**, an inner upper skin **38**, a core **32**, an inner lower skin **40** and an outer lower skin **36**. The core **32** corresponds to the core **22** described with respect to Figure **2**. Also, the skins **34, 36, 38, 40**
30 correspond to the skins **24, 26** described with respect to Figure **2**. Pairs of upper and lower skins **34, 38** and **36, 40** may be provided to increase strength. The skins may be laid up in an aligned manner, or with their plies rotated (e.g., the

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warp and weft of the outer upper skin **34** may have its warp and weft rotated through **90** degrees relative to those of the inner upper skin **38**).

Methods of manufacture of aircraft interior panels according to the present invention will now be described. For the sake of simplicity, three-layer green aircraft interior panels will be described although it will be readily appreciated that the method may be simply extended to panels having more than three layers.

A simple method of manufacture is shown in Figure 4. At **100**, skins **24**, **26** are formed. This step **100** comprises laying up natural fibre fabrics, as indicated at **102**. For example, one layer of flax fabric is laid up for each skin **24**, **26**. At **104**, a thermoset inorganic resin impregnates the natural fibres and the skins are formed **24**, **26** by curing the mixture. For example, an aluminium silicate derivative is used as the inorganic thermoset resin and may be mixed with a hardener. In addition, an anti-shrinkage additive may be used. The aluminium silicate derived compound used as filler added in a **1** to **15%** by weight has been found to work well. The natural fibre fabric impregnated with the thermoset resin may be introduced into a vacuum bag and vacuum pumped to extract the air. The skin is cured for a period in between **30** min to **24** hours without vacuum pumping, at a temperature in the range of **25** to **80** degrees Centigrade, under atmospheric pressure or pressurized in mechanical press or in an autoclave to compact the composite. This may be followed by curing at room temperature until constant weight is achieved, with vacuum pumping to remove water from the composite.

With the skins **24**, **26** formed in this manner, they are laid up on both sides of the core **22**, as shown at step **106**. A skin **24**, **26** is placed on each side of the core **22**, applying an adhesive between the skin and the core surface. Environmentally friendly adhesives (low volatile organic compounds) have been found to work well. In this embodiment, the core **22** comprises a PVDF foam. At **108**, the complete sandwich panel **20** may be formed by curing the adhesive in a low temperature vacuum bag process, under atmospheric pressure, or pressurized in a mechanical press or in an autoclave to compact the panel **20**.

Figure 5 shows a further embodiment of a method of manufacture according to the present invention. At **200**, skins **24**, **26** are formed. A first step

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201 comprises treating the natural fibres with fire retardant. For example, natural fibres may be formed into fabrics and immersed in a concentrated solution of fire retardant at **25-80** degrees Centigrade for **20** to **80** minutes. The soaked natural fibre fabrics may then be dried at room temperature by hanging the fabrics vertically until they achieve a constant weight. It has been found that the natural fibres made this way retain **10%** to **30%** of flame retardant by weight.

The method then continues in much the same way as previously described with respect to Figure 4. The treated natural fibres are laid up at **202**, and impregnated with a thermoset inorganic resin at **204**. The thus-formed skins **24**, **26** are bonded with the core **22** at **206**, and formed into the finished aircraft interior panel **20** at **208**.

The methods of manufacture described with respect to Figures 4 and 5 comprise a two-stage panel assembly process, where the skins **24**, **26** are first formed and then the complete aircraft interior panel **20** is assembled. However, any of these methods may be modified to use a one-step formation process where the skins **24**, **26** and complete panel **20** are cured in just a single process.

For example, Figure 6 shows the method of Figure 4 adapted to use a single step of curing. At step **305**, the surface of the core **22** is activated to improve the adhesion between the core **22** and the skins **24**, **26**. The treatment may comprise exposing the PVDF core **22** to an atmospheric pressure air dielectric barrier discharge (DBD). The DBD reactor may be equipped with a sinusoidal waveform high voltage alternating current power supply, operating at **40** to **80** Hz. The output power and impedance of the operational working load are variable and controllable. The discharge may be generated between stationary electrodes and a sliding platen on which the foam core **22** is mounted. The electrodes may be formed from steel rods around which are wound **1.5** mm diameter bare stainless steel wire. The platen may be **10** mm thick and may have a silicon-rubber coating. Four cycles at **0.87** kW power and a speed of **40** m per minute might be used, equivalent to a power density of **4.9** W/cm². This treatment has been found to activate the surfaces of the core **22** making them more chemically reactive such that adhesion between the core **22** and the skins **24**, **26** is significantly improved.

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At **302**, natural fibre fabrics like those described above are laid up. A thermoset resin, like that described above, impregnates the two natural fibre fabrics, as indicated in step **304**. At **306**, one fibre fabric is laid up on one side of the core **22** with the other fibre fabric being laid up on the other side of the core **22**. The aircraft interior panel **20** is then assembled in a single step at **308** using a vacuum bag process. In such a way the composite skins **24**, **26** form and bond to the core in just a single step. The panel **20** may be introduced into a vacuum bag and vacuum pumped to extract the air. The panel **20** may then be cured for **30** min to **24** hours without vacuum pumping at **25-80** degrees Centigrade under atmospheric pressure or pressurized in a mechanical press or in an autoclave to improve the composite consolidation. This may be followed by curing at room temperature until constant weight is achieved, with vacuum pumping to remove water from the composite.

Figure **7** shows an adaptation of Figure **5** as a single cure process. At **401**, the natural fibre fabrics are treated with the flame retardant, as previously described. At **405**, the core is treated with DBD, as previously described. The treated fibre fabrics are then laid up as indicated at step **402** and a thermoset inorganic resin, like those described above, impregnates the fibre fabrics at step **404**. At **406**, one fibre fabric is laid up on one side of the core **22** and the other fibre fabric is laid up on the other side of the core **22**. The complete aircraft interior panel **20** is then formed in a single step using a vacuum bag process, as indicated at **408**.

In addition to Figures **6** and **7**, it will now be readily understood that the methods of the previous Figures may be adapted to use a single curing step in a similar fashion, as too can other variants of the general method.

Figure **2** shows an aircraft interior panel **20** having upper skin **24** and lower skin **26** formed from an inorganic thermoset resin. Embodiments using thermoplastic resins will now be described, along with example methods of manufacture.

Figure **8** shows an aircraft interior panel **80** comprising a sandwich structure. A core **82** is sandwiched between an upper skin **84** and a lower skin **86**. Upper skin is provided with a protective coating **88**.

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The core **82** comprises a fire resistant thermoplastic foam. The core **82** may have a thickness of **4** to **5** mm. In alternative embodiments, the core **82** comprises a paper honeycomb. Paper honeycomb cores may have a thickness of **10mm**, or even greater.

5 The upper skin **84** and lower skin **86** are of corresponding construction. They both comprise natural fibres, such as flax, set within a thermoplastic resin. The natural fibres may be as previously described with respect to Figures **2** and **3**. The thermoplastic resin used in the embodiment of Figure **8** is polypropylene.

10 The composite matrix may be modified with a non-halogenated flame retardant. For example, ammonium polyphosphate (**50%** concentration) and nanographene (**5%** concentration) may be added to the polypropylene matrix. Compatibilizers may be added to improve the incorporation of the flame retardants into the matrix. In addition, the natural fibres may be treated with a flame retardant, namely non-halogenated nano-particle flame retardants such as
15 nano-phosphates thereby forming a protective coating over the natural fibres.

 In the embodiment of Figure **8**, the upper skin **84** is provided with a protective coating **88**. In alternative embodiments, lower skin **86** is also provided with a protective coating **88**. The protective coating **88** may be a fireproof nano-coating. Where applied to only one skin **84** or **86**, this skin **84** or **86** will be the
20 cabin-side skin when the aircraft interior panel **80** is installed in an aircraft.

 The protective coating **88** is applied to the upper skin **84** that is formed from a polypropylene resin. The protective coating **88** comprises two protective layers although, for the purposes of clarity, only a single layer is shown in Figure **8**. Each layer comprises nano-particles of sodium nano-silicate encapsulated
25 within aluminium nano-particles, and the two layers are applied in turn.

 In some embodiments, aircraft interior panels **80** are not provided with protective coating **88**.

 Figure **9** shows another embodiment of an aircraft interior panel **90** comprising a thermoplastic resin. The aircraft interior panel **90** comprises a core
30 **92** sandwiched between an upper skin **94** and a lower skin **96**. The outer surfaces of both the upper skin **94** and the lower skin **96** are provided with a protective coating **98**, although in some cases only one of the skins **94** or **96** may

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need to be provided with a protective coating **98**. In fact, in some embodiments, neither the upper skin **94** nor the lower skin **96** need to be provided with a protective coating **98**.

5 The core **92** comprises a fire resistant thermoplastic foam. The core **92** may have a thickness of **4** to **5** mm. In alternative embodiments, the core **92** comprises a paper honeycomb. Paper honeycomb cores may have a thickness of **10**mm, or even greater. In alternative embodiments, the core **92** comprises balsa wood.

10 The upper skin **94** and lower skin **96** are of corresponding construction. They both comprise natural fibres, such as flax, set within a thermoplastic resin. The natural fibres may be as previously described with respect to Figures **2** and **3**. The thermoplastic resin used in the embodiment of Figure **9** is polylactic acid.

15 The composite matrix may be modified with a non-halogenated flame retardant. For example, ammonium polyphosphate (**25%** concentration), zinc borate (**5%** concentration) and nanographene (**1%** concentration) may be added to the polylactic acid matrix. Optionally, compatibilizers are also added to improve the incorporation of the flame retardants into the matrix. In addition, the natural fibres may be treated with a flame retardant, namely non-halogenated nano-particle flame retardants such as nano-phosphates thereby forming a
20 protective coating over the natural fibres.

In the embodiment of Figure **9**, the upper skin **94** and lower skin **96** are both provided with the corresponding protective coatings **98**. The protective coating **98** may be a fireproof nano-coating. The protective coating **98** may comprise nano-particles of sodium nano-silicate encapsulated within aluminium
25 nano-particles, ammonium salts, nano-graphene, sodium carbonate or sodium silicate.

Further embodiments of methods of manufacture will now be described with reference to Figures **10** and **11**. These methods of manufacture may be used to manufacture aircraft interior panels according to the present invention,
30 and any of the embodiments of aircraft interior panels **20**, **30**, **80**, **90** described above. However, the following methods are particularly preferred for the

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manufacture of aircraft interior panels according to the embodiments of Figures 8 and 9.

A fifth embodiment of a method of manufacture of aircraft interior panels is shown in Figure 10. As an example, it is described with respect to the aircraft interior panel 80 of Figure 8, although the method may be applied to any aircraft interior panel constructed in accordance with the present invention. The method of manufacture of Figure 10 is similar to that of Figure 5 previously described. It is a two-stage panel assembly process, where the skins 84, 86 are first formed and then the complete aircraft interior panel 80 is assembled.

At 500, skins 84, 86 are formed. A first step 501 comprises treating the natural fibres, flax in this embodiment, with the fire retardant. For example, natural fibres may be formed into fabrics. The natural fibres may be immersed in a concentrated solution of fire retardant nano-particles (e.g., nano-phosphates). This retardant may be used with any aircraft interior panel in accordance with the present invention, including all the embodiments described herein. The natural fibres may be immersed for 30 seconds and then dried in an oven at 60 degrees Centigrade for 30 minutes. This treatment may be repeated several times to increase the concentration of flame retardant.

The method then continues at step 502 that comprises laying up the flame retardant coated natural fibre fabrics. For example, one layer of fabric is laid up for each skin 84, 86. At 504, a thermoplastic inorganic resin mix is used to impregnate the natural fibres. This resin mix comprises polypropylene resin (41% concentration) and, to increase fire resistance, ammonium polyphosphate (50% concentration) and nanographene (5% concentration) are added to the polypropylene matrix. A compatibilizer (4% concentration) may be added, such as a small concentration of Integrate NP 507-030 coupling agent to improve the compatibility between the matrix, the fire retardant additives and the natural fibre fabric. This resin mix may be extruded to obtain polymeric sheets 200 µm thick or less that are combined with the natural fibre fabrics.

To form the skins 84, 86, a flax fibre fabric may be sandwiched between a pair of the extruded sheets of resin mix. This laminate may then held at a

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temperature of **200** degrees Centigrade and a pressure of **87** kN for **1** minute, and the resulting skins **84**, **86** may then be allowed to cool to room temperature.

5 With the skins **84**, **86** formed in this manner, they are laid up on both sides of the core **82**, as shown at step **506**. A skin **84**, **86** is placed on each side of the thermoplastic foam core **82**, and a fire-proof adhesive is applied between the skin and the core surface. Polyurethane-based adhesives and epoxy-based adhesives are good choices for the adhesive. At **508**, the complete aircraft interior panel **80** is formed by curing the adhesive.

10 At step **510**, a protective coating may be added to the upper skin **84**. First, the outer surface of the upper skin **84** may be activated by chemical etching, to allow improved adherence of the nano-coating to the outer surface. The nano-coating used in this embodiment comprises sodium silicate nano-particles encapsulated within aluminium nano-particles. This coating may be used with any aircraft interior panel in accordance with the present invention, including all
15 the embodiments described herein. This coating may be applied to the activated outer surface of the upper skin **84** by manual impregnation of the surface with the nano-particle dissolution. A first layer may be applied and then dried in an oven at **40** degrees Centigrade for **10** minutes. Then, a second layer may be applied in the same way, and dried in an oven at **40** degrees Centigrade for **30** minutes.
20 The aircraft interior panel **80** is thus complete.

The method of Figure **10** may be adapted to form the aircraft interior panel **90** of Figure **9**, as follows.

25 At **600**, skins **94**, **96** are formed. At step **601** the natural fibres, flax in this embodiment, may be treated with fire retardant. For example, natural fibres may be formed into fabrics. The natural fibres may be immersed in a concentrated solution of fire retardant nano-particles (e.g. nano-phosphates). This retardant may be used with any aircraft interior panel in accordance with the present invention, including all the embodiments described herein. The natural fibres may be immersed for **30** seconds and then dried in an oven at **60** degrees
30 Centigrade for **30** minutes, as has already been described with respect to Figure **10**. This treatment may be repeated several times to increase the concentration of flame retardant.

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The method then continues at step **602** for laying up of the flame retardant coated natural fibre fabrics, such as by laying up one layer of fabric for each skin **94, 96**. At **604**, a thermoplastic inorganic resin mix is used to impregnate the natural fibres. In this embodiment, this resin mix comprises polylactic acid resin
5 (69% concentration) and, to help fire resistance, aluminium polyphosphate (25% concentration), zinc borate (5% concentration) and nanographene (1% concentration) are added to the matrix. This resin mix may be extruded to obtain polymeric sheets **200** μm thick or less that are combined with the natural fibre fabrics.

10 To form the skins **94, 96**, a flax fibre fabric may be sandwiched between a pair of the extruded sheets of resin mix. This laminate may then be held at a temperature of **140** degrees Centigrade and a pressure of **87** kN for **1** minute, and the resulting skins **94, 96** may then be allowed to cool to room temperature.

With the skins **94, 96** formed in this manner, they are laid up on both sides
15 of the core **92**, as shown at step **606**. A skin **94, 96** is placed on each side of the thermoplastic foam core **92**, and a fire-proof adhesive such as a polyurethane-based or epoxy-based adhesive, is applied between the skin and the core surface. At **608**, the complete aircraft interior panel **90** is formed by curing the adhesive.

20 At step **610**, protective coatings may be added to the upper and lower skins **94, 96**. The method is as described at step **510** of Figure 5. In summary, the outer surface of each skin **94, 96** may be activated by chemical etching and a nano-coating may be applied. The nano-coating of this embodiment comprises nano-particles of phosphates, ammonium salts, nanographene, carbonate and
25 sodium silicate. A small quantity of acrylic resin may be added to improve the flexibility, adherence and thermal stability of the protective coating. This coating may be used with any aircraft interior panel in accordance with the present invention, including all the embodiments described herein. The coating may be applied in two layers by manual impregnation. A first layer may be applied and
30 then dried for **10** minutes at **40** degrees Centigrade, and a second layer may be applied and dried at the same temperature for **30** minutes. The aircraft interior panel **90** is thus complete.

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The methods of manufacture described with respect to Figures 10 and 11 comprise two-stage panel assembly processes, where the skins 84, 86, 94, 96 are first formed and then the complete aircraft interior panels 80, 90 are assembled. However, these methods may be modified to a one-step formation processes where the skins 84, 86, 94, 96 and complete panels 80, 90 are cured in just a single process similar to as has already been described with respect to Figures 6 and 7.

It will be clear to the skilled person that variations may be made to the above embodiments without necessarily departing from the scope of the invention that is defined by the appended claims.

For example, the methods described above with respect to three-layer aircraft interior panels 20 may be readily adapted to more than three-layer aircraft interior panels. For example, the number of skin layers laid up on the core may be increased from one each side. More than a single core layer may also be included.

Various aircraft interior panels and various methods of manufacture have been described. It will be appreciated that the different methods may be applied to make any of the different panels described.

20 Examples

Example structures will now be described and their heat resistant behaviour presented.

The fire resistance of the skins were tested against the FAA and EASA requirements for aircraft interiors. Skins comprising an aluminium silicate derivative inorganic thermoset matrix and natural fibre composite, with the natural fibres containing in between 10 to 30% by weight boron derivative flame retardant, were exposed to radiant heat. Three samples were hung vertically in an environmental chamber. A constant air flow was passed through the chamber. The samples' exposures were determined by a radiant heat source adjusted to produce the desired total heat flux on the specimen of 3.5 W per cm². Combustion was initiated using a piloted ignition. The combustion products

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leaving the environmental chamber were monitored and used to calculate the release rate of heat.

5 Figure **12** is a table presenting the results for the three sample skins made of an inorganic thermoset resin. The heat release peak and the total heat release after two minutes are well within the limits set by the Federal Aviation Administration (FAA). Figure **13** is a graph showing an averaged heat release with time for these samples.

10 Four sandwich panels made of an inorganic thermoset resin were also constructed and tested. Figure **14** is a table setting out the composition of each sandwich panel, along with the results of the heat release tests. The tests were performed in the same way as for the skin samples described above. Again, the peak and total heat release was found to be well within the FAA requirements. Figure **15** is a graph of heat release with time.

15

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An aircraft interior panel comprising:
 - 5 a core sandwiched between first and second skins;

wherein the first and second skins both comprise a composite matrix of flax fibres set within a resin and wherein the flax fibres are pretreated with a non-halogenated flame retardant prior to being set in the resin, said flame retardant being of a concentration sufficient
10 to limit a heat release of the panel to a maximum heat release rate of less than $65 \text{ kW}\cdot\text{m}^{-2}$ and a total heat release during the first 2 minutes of less than $65 \text{ kW}\cdot\text{min}\cdot\text{m}^{-2}$ when exposed to $3.5 \text{ W}\cdot\text{cm}^{-2}$ heat flux.
- 15 2. The aircraft interior panel of claim 1, wherein the flame retardant comprises disodium octaborate tetrahydrate.
3. The aircraft interior panel of any one of claims 1 or 2, wherein the resin comprises an inorganic thermoset resin.
4. The aircraft interior panel of claim 3, wherein the inorganic thermoset resin comprises an aluminium silicate derivative.
- 20 5. The aircraft interior panel of any one of claims 1 to 4, wherein the resin comprises a thermoplastic resin.
6. The aircraft interior panel of claim 5, comprising a flame retardant protective coating on an outer surface of at least one of the first and second skins.
- 25 7. The aircraft interior panel of claim 6, wherein the resin comprises polypropylene and the protective coating comprises sodium silicate nanoparticles encapsulated within aluminium nanoparticles.

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8. The aircraft interior panel of claim 6, wherein the resin comprises polylactic acid and the protective coating comprises nano-particles of at least one of phosphates, ammonium salts, nanographene, carbonate and sodium silicate.
- 5 9. The aircraft interior panel of claim 5, wherein the thermoplastic resin comprises at least one of polypropylene and polylactic acid.
10. The aircraft interior panel of any one of claims 1 to 9, wherein the core comprises one of a paper honeycomb and a thermoplastic foam.
- 10 11. The aircraft interior panel of claim 10, wherein the thermoplastic foam comprises a polyvinylidene fluoride foam.
12. The aircraft interior panel of any one of claims 1 to 11, wherein the core has been activated to enhance adhesion to the first and second skins.
13. The aircraft interior panel of claim 12, wherein the core is activated by one of a dielectric barrier discharge process, chemical etching, and an adhesive.
- 15 14. An aircraft comprising one or more aircraft interior panels according to any one of claims 1 to 13.
15. A method of manufacturing the aircraft interior panel of any one of claims 1 to 13, the method comprising:
 - 20 pretreating the flax fibers by immersing the flax fibres in the non-halogenated flame retardant;
 - curing a stack of the pretreated flax fibres, the resin and the core so as to form the aircraft interior panel.
- 25 16. The method of claim 15, further comprising laying up the flax fibres, impregnating the flax fibres with the resin, curing the flax fibres and resin to form the first and second skins, laying up the first and second skins on

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each side of the core to form a stack, and curing the stack to form the aircraft interior panel.

- 5 **17.** The method of claim **16**, wherein laying up the flax fibres comprises laying up flax fibre fabrics impregnated with the resin on both sides of the core to form the stack, and wherein curing the stack comprises curing the stack in one step to form the aircraft interior panel.
- 10 **18.** The method of any one of claims **15** to **17**, wherein curing comprises curing by using a vacuum bag process, a mechanical press or an autoclave.
- 10 **19.** The method of any one of claims **15** to **18**, further comprising providing a flame retardant protective coating on an outer surface of at least one of the first and second skin.
- 15 **20.** The method of any one of claims **15** to **19**, further comprising activating the surface of the core or using adhesives to improve adhesion of the core to the first and second skins.

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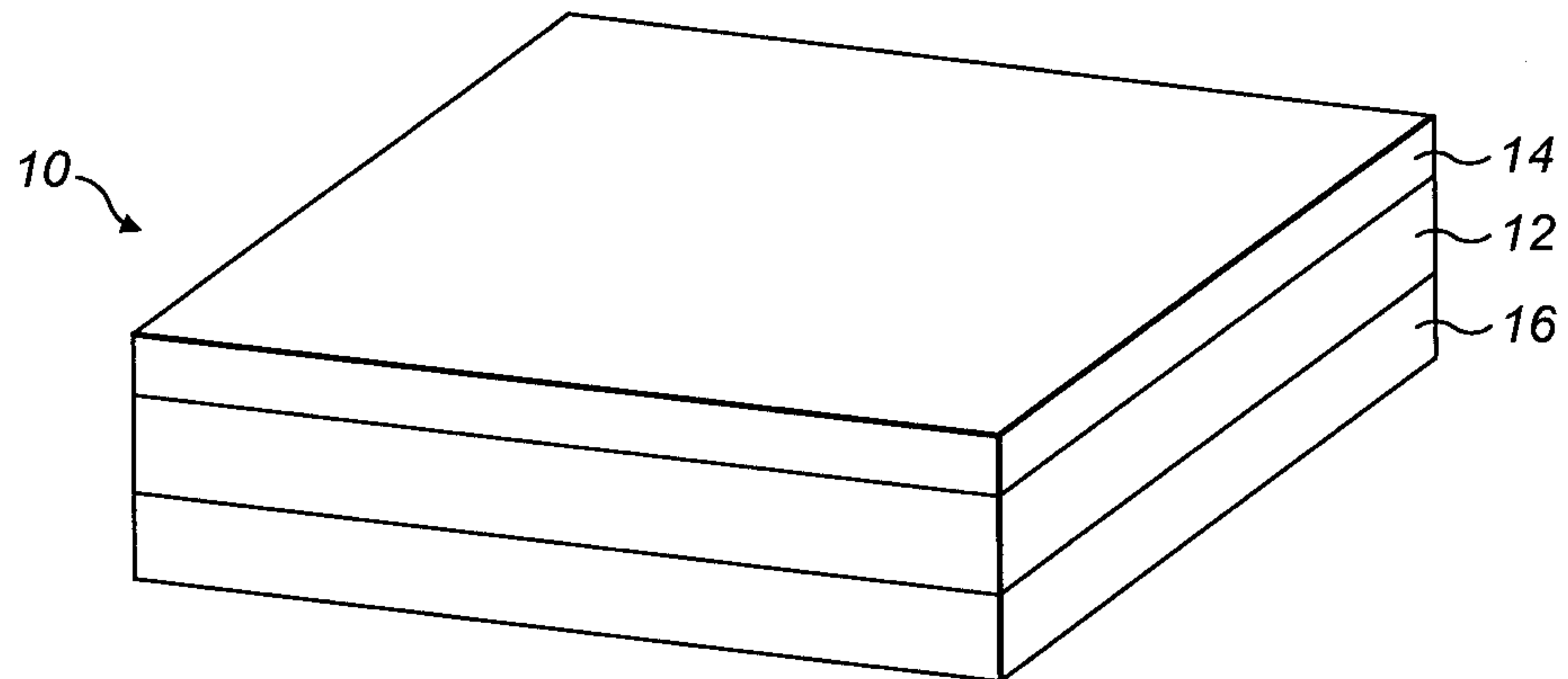


FIG. 1
Prior Art

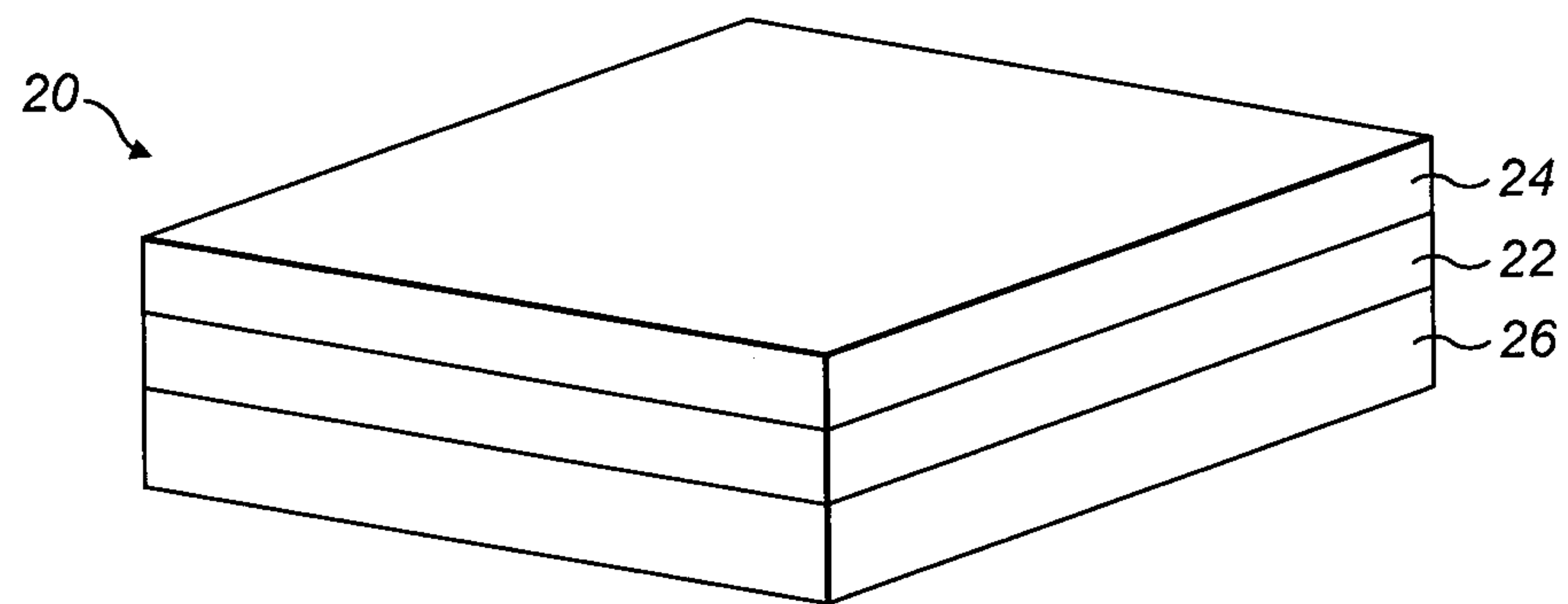


FIG. 2

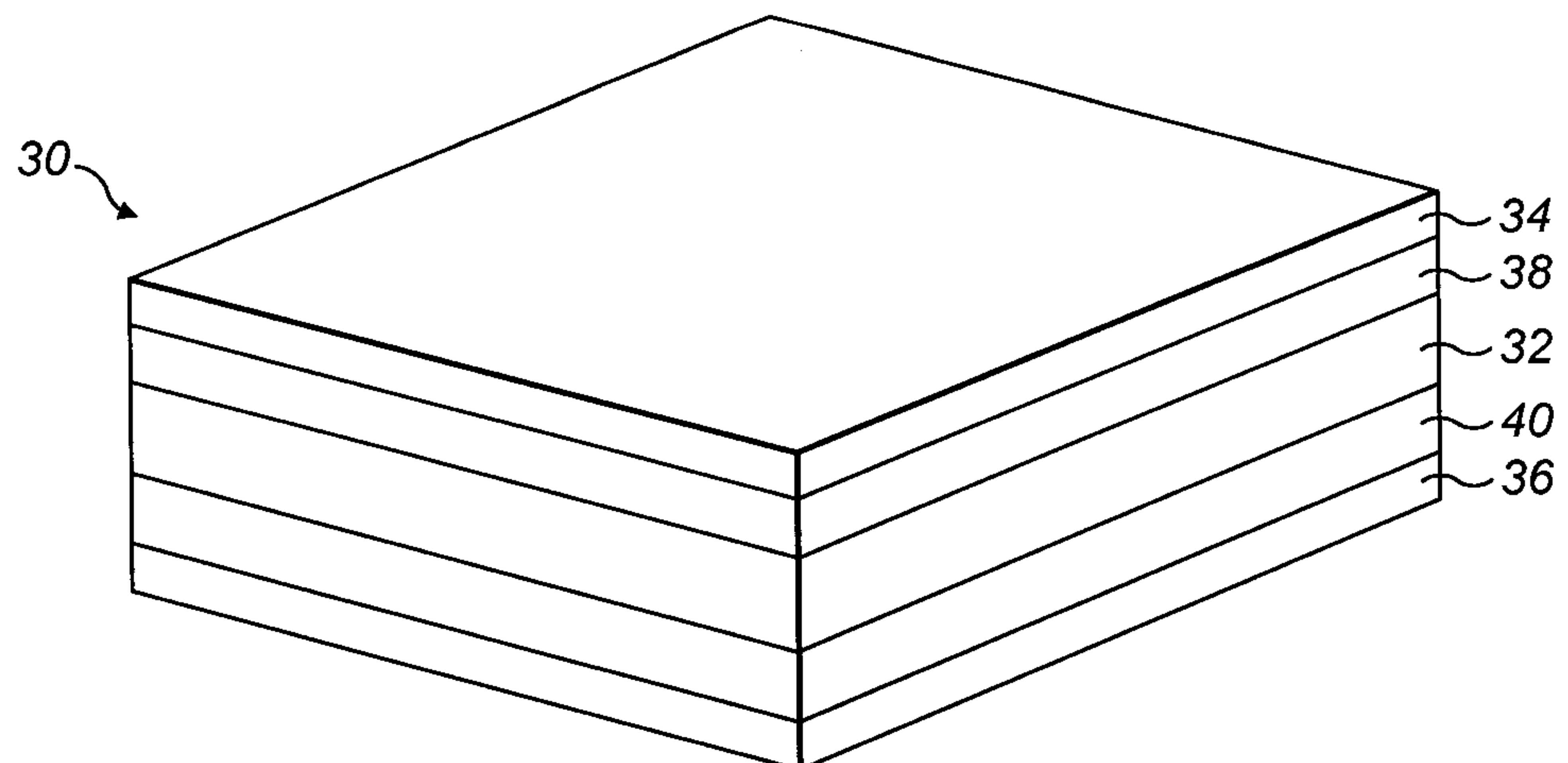
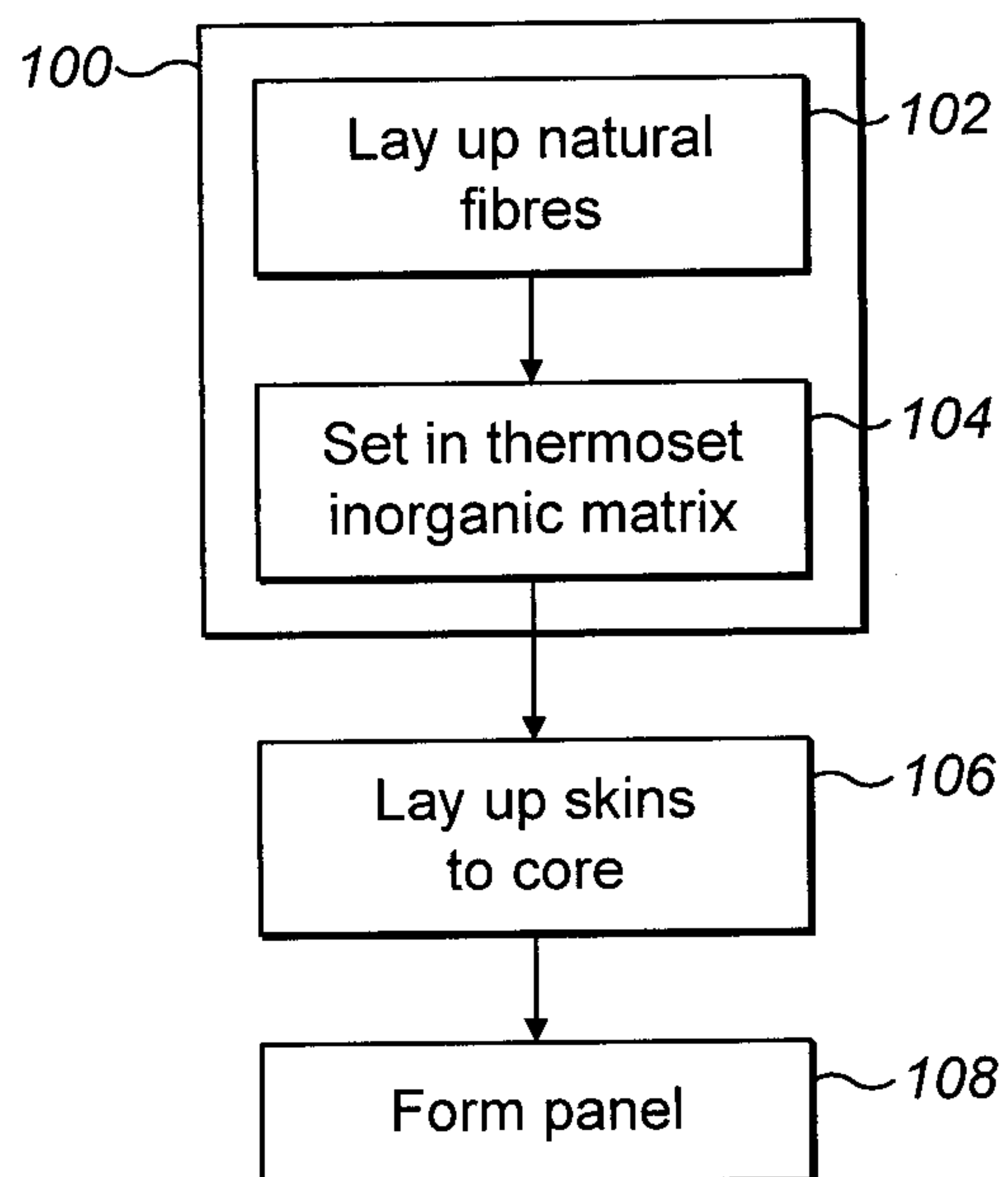
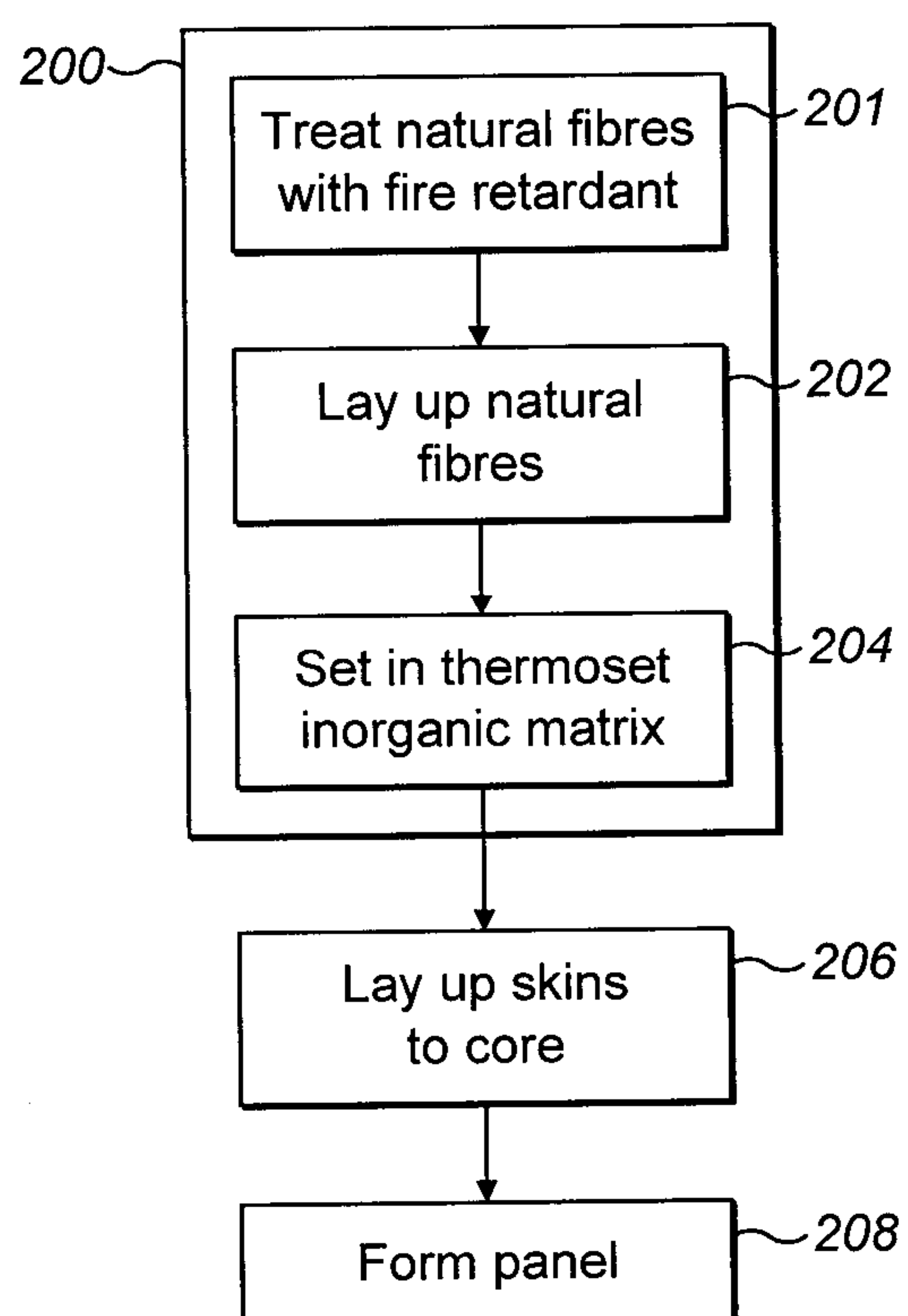
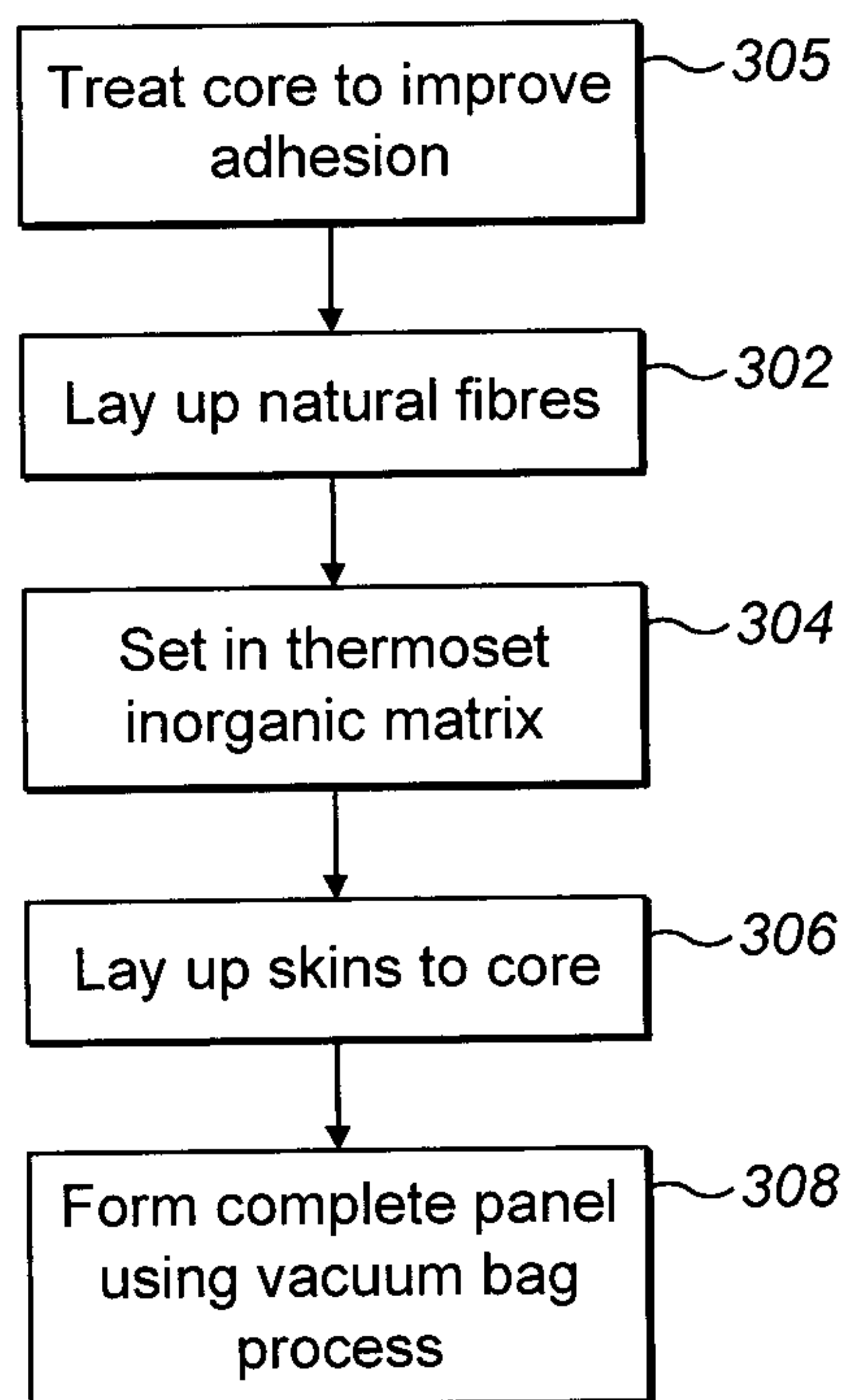
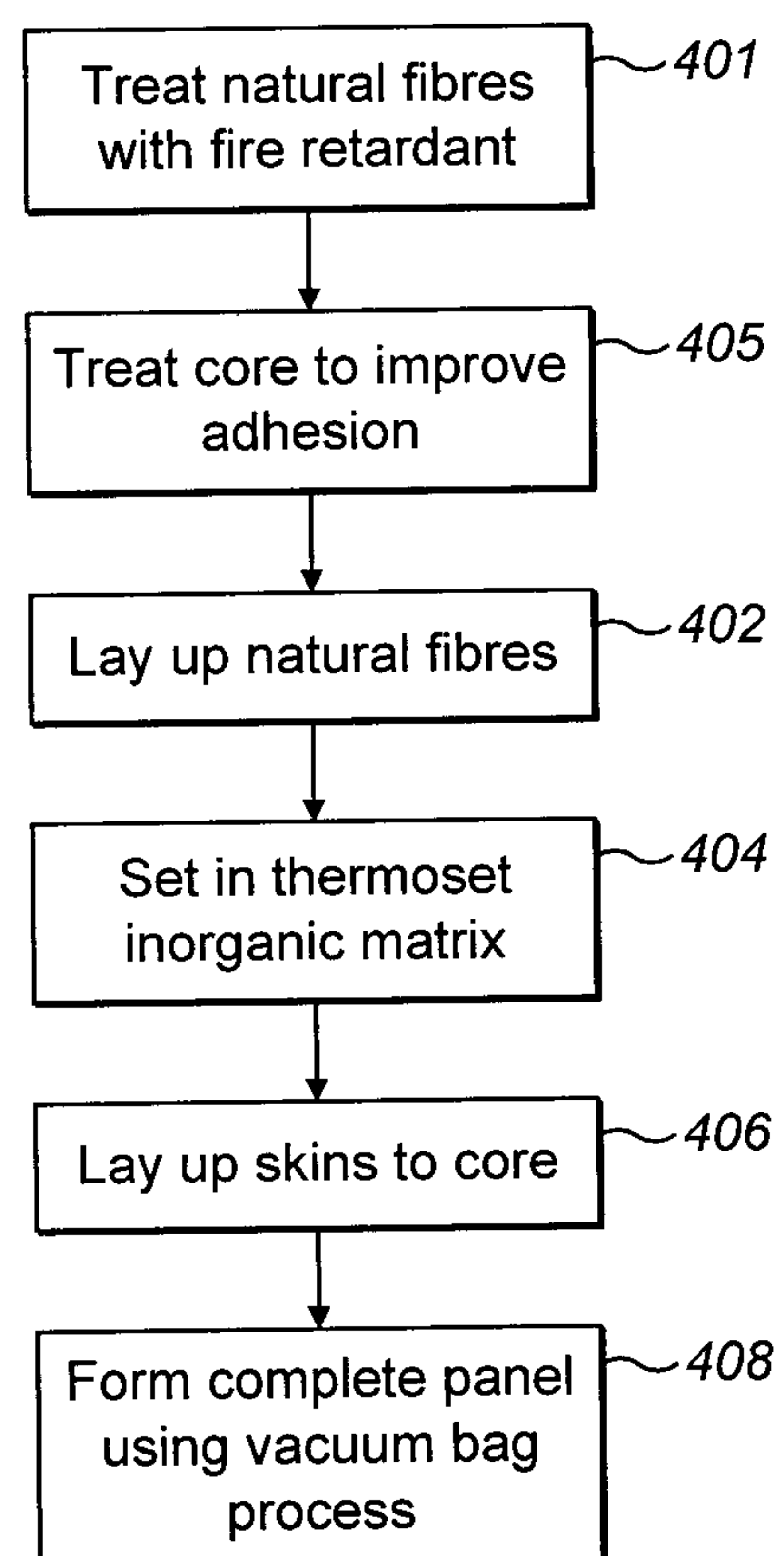


FIG. 3

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**FIG. 4****FIG. 5**

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**FIG. 6****FIG. 7**

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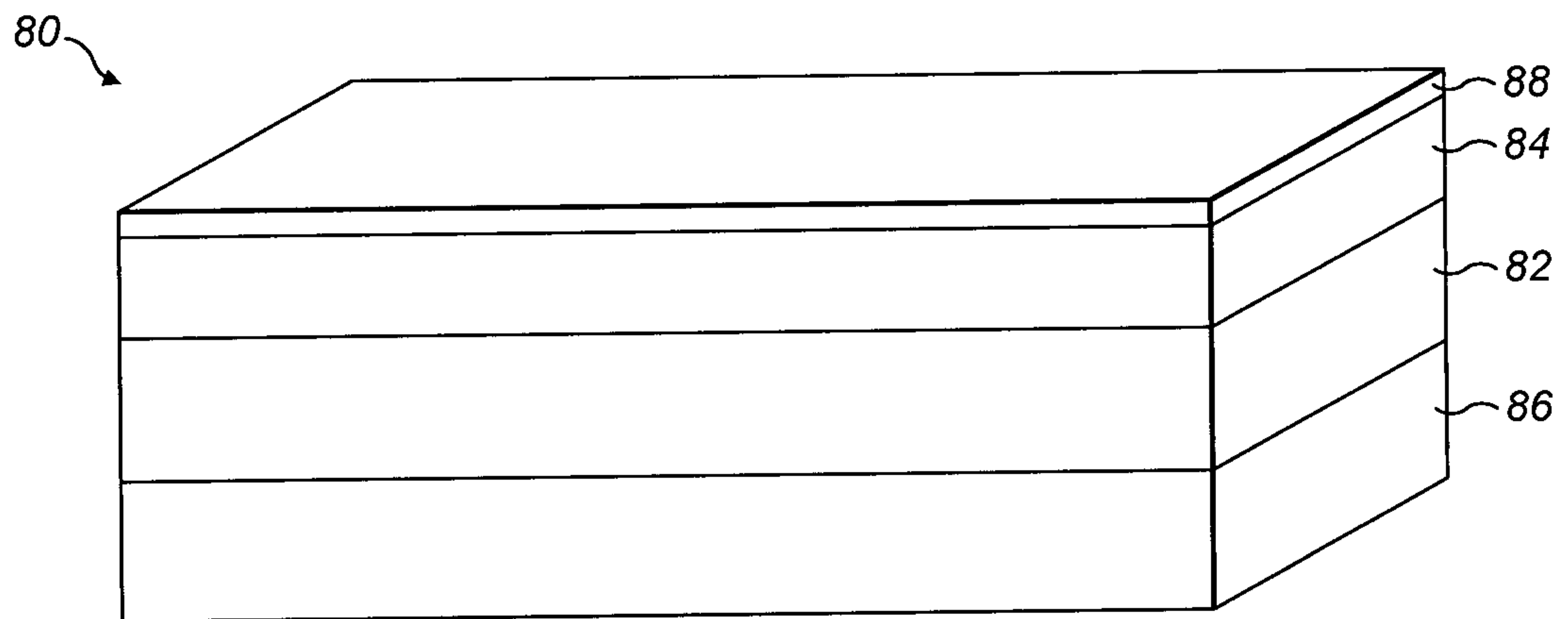


FIG. 8

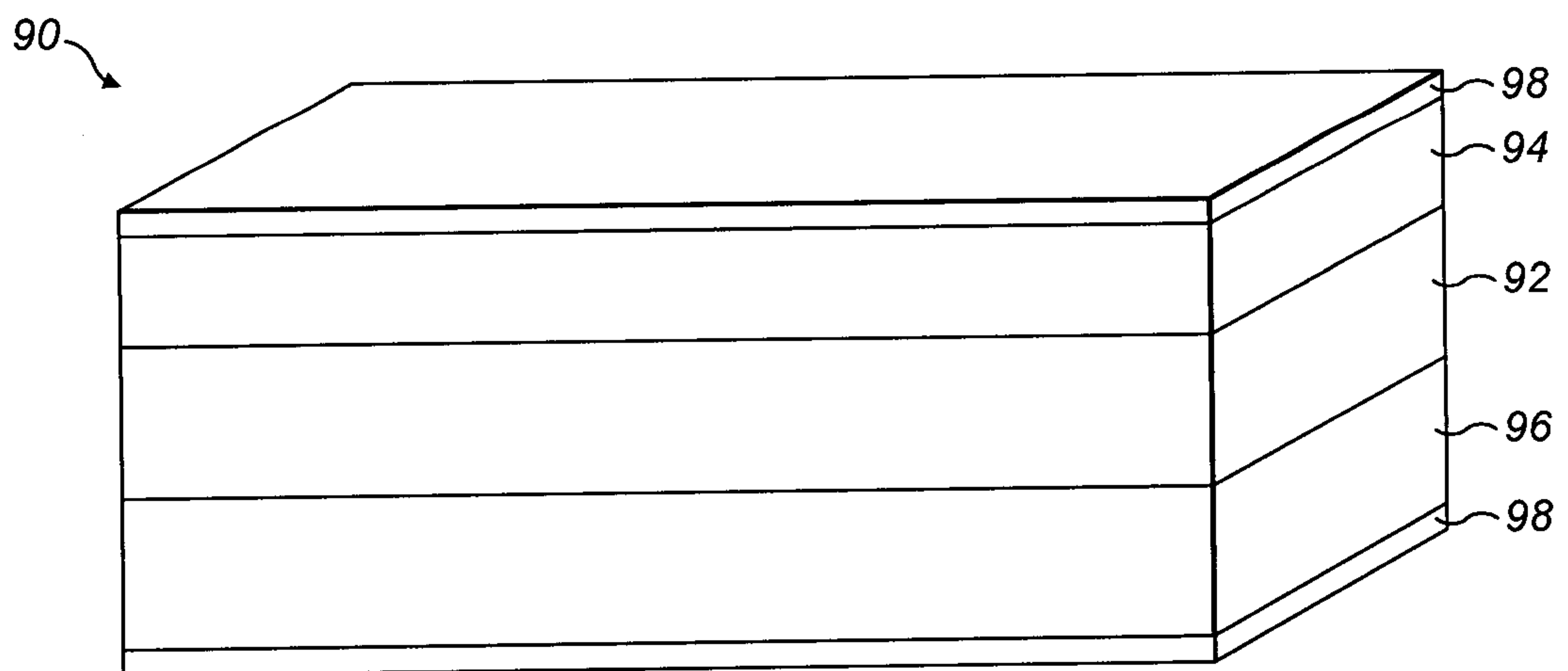
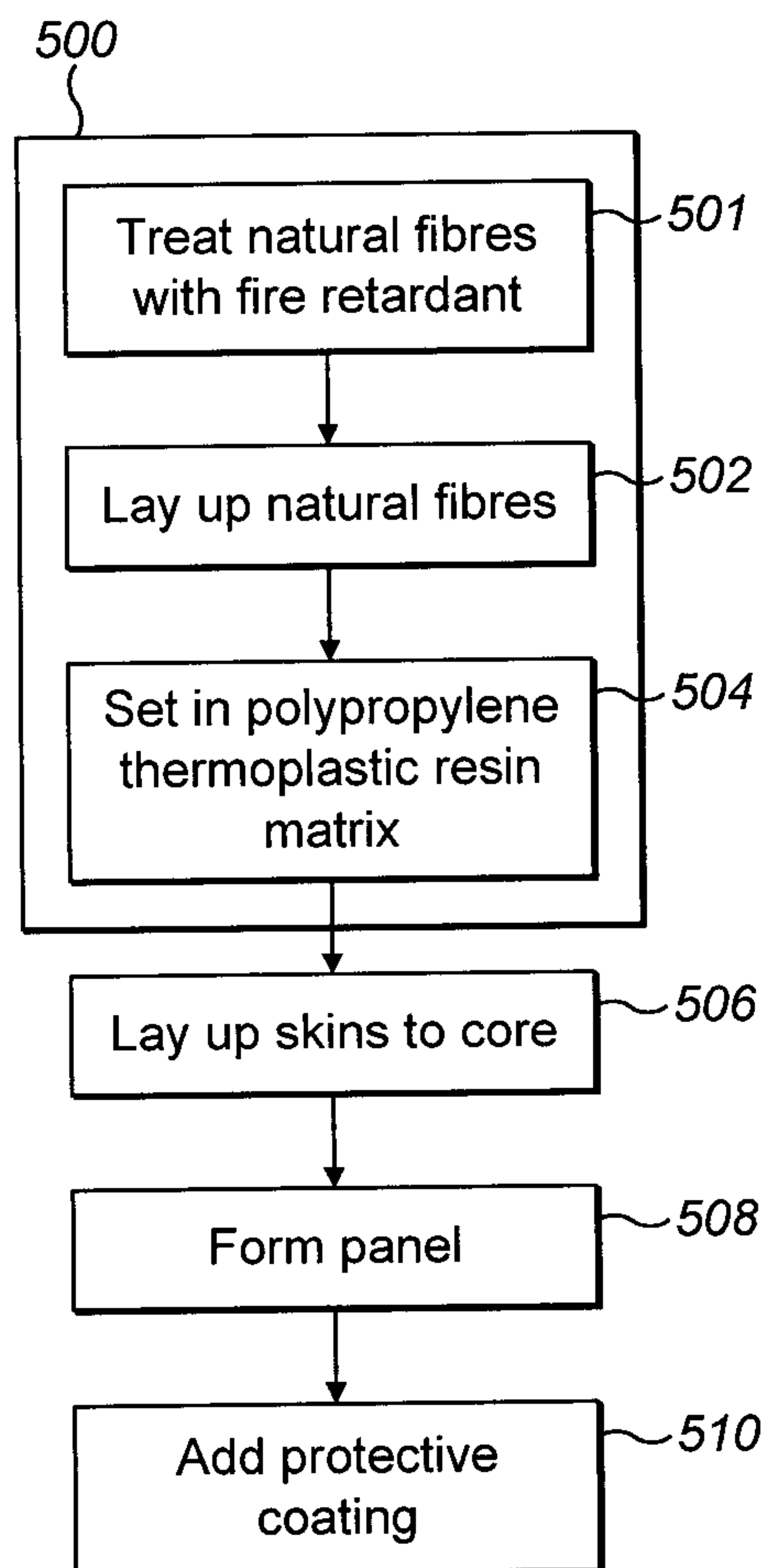
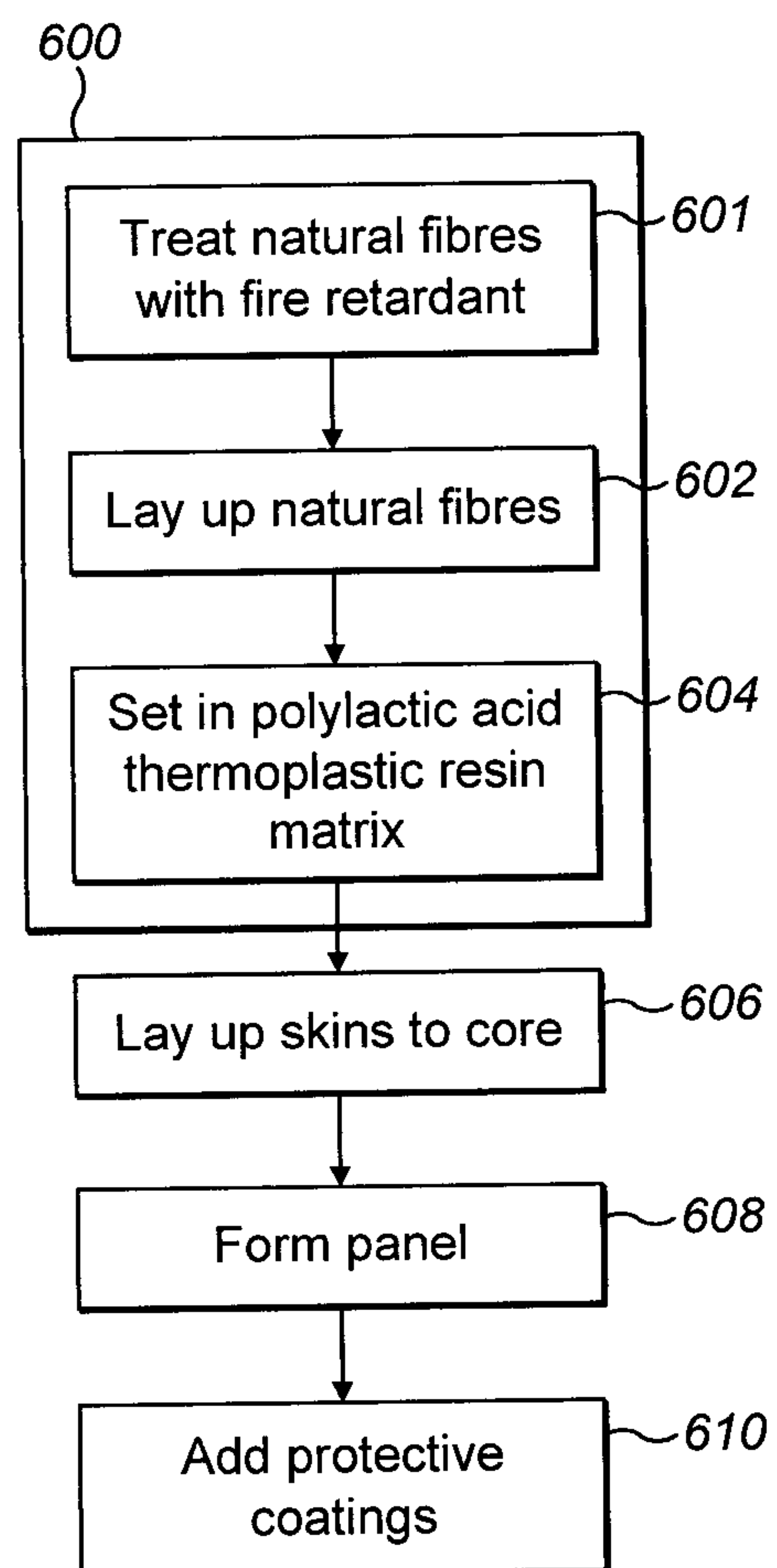


FIG. 9

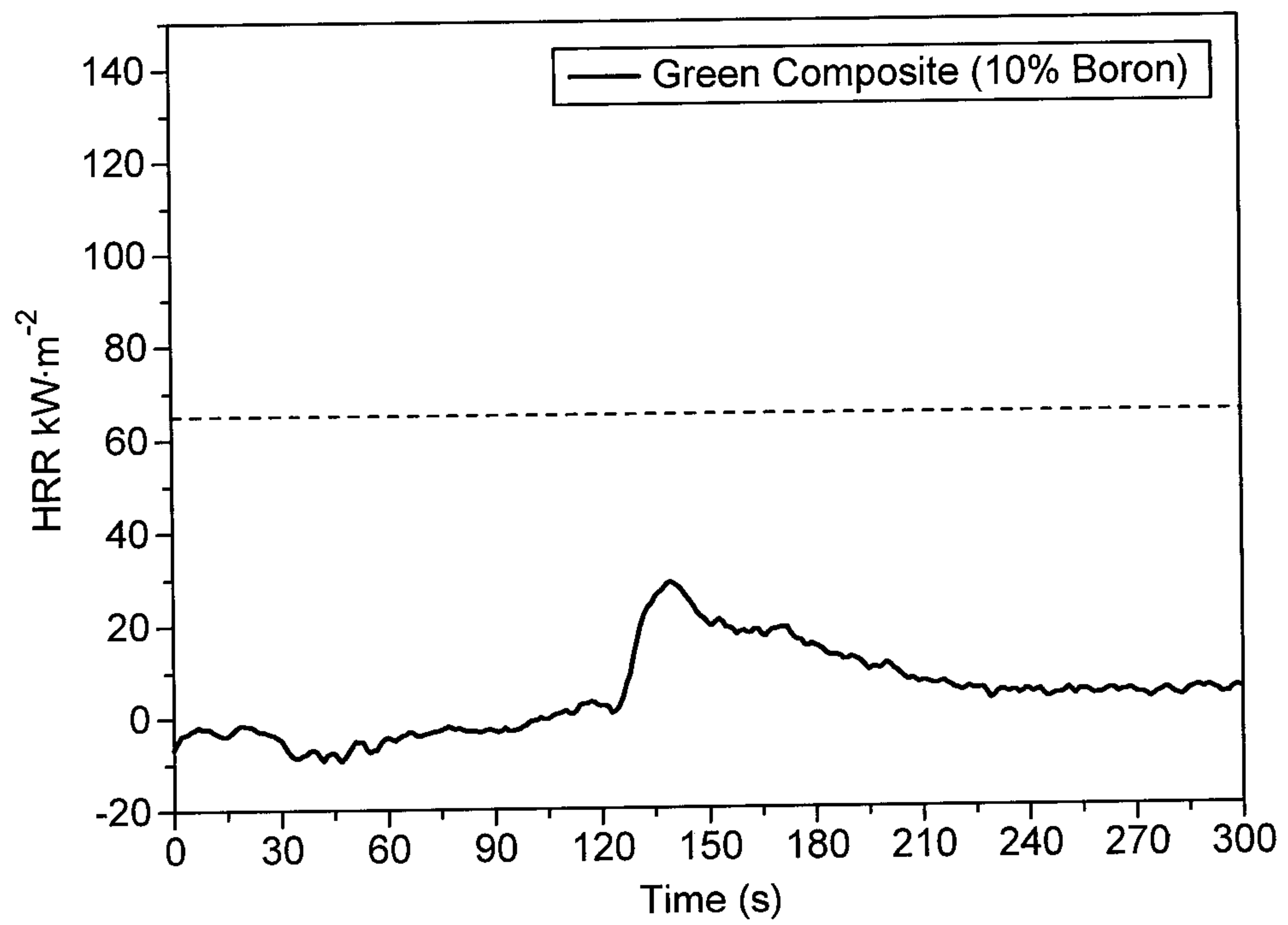
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**FIG. 10****FIG. 11**

	S01	S02	S03	Average
Fibre:				
Initial mass of fibre (g)	31.2	30.2	30.5	30.6
Final mass fibres + boron derivate flame retardant (g)	41.7	40.1	40.8	40.9
% wt boron derivate flame retardant	25.2%	24.7%	25.2%	25.0%
Composite:				
Resin mass (g)	73.4	73.4	73.4	73.4
Hardener mass (g)	11.0	11.0	11.0	11.0
% wt hardener	13.0%	13.0%	13.0%	13.0%
Total mass (dry) (g)	107.5	100.1	101.2	102.9
% wt fibre (dry)	29.0%	30.2%	30.1%	29.8%
% wt boron derivate flame retardant (dry)	9.8%	9.9%	10.2%	10.0%
Maximum heat release rate (kW*m ⁻²)	34.2	27.0	28.7	30.0
Total heat release during the first 2 min (kW*min*m ⁻²)	-8.3	-6.5	-6.5	-7.1

FIG. 12

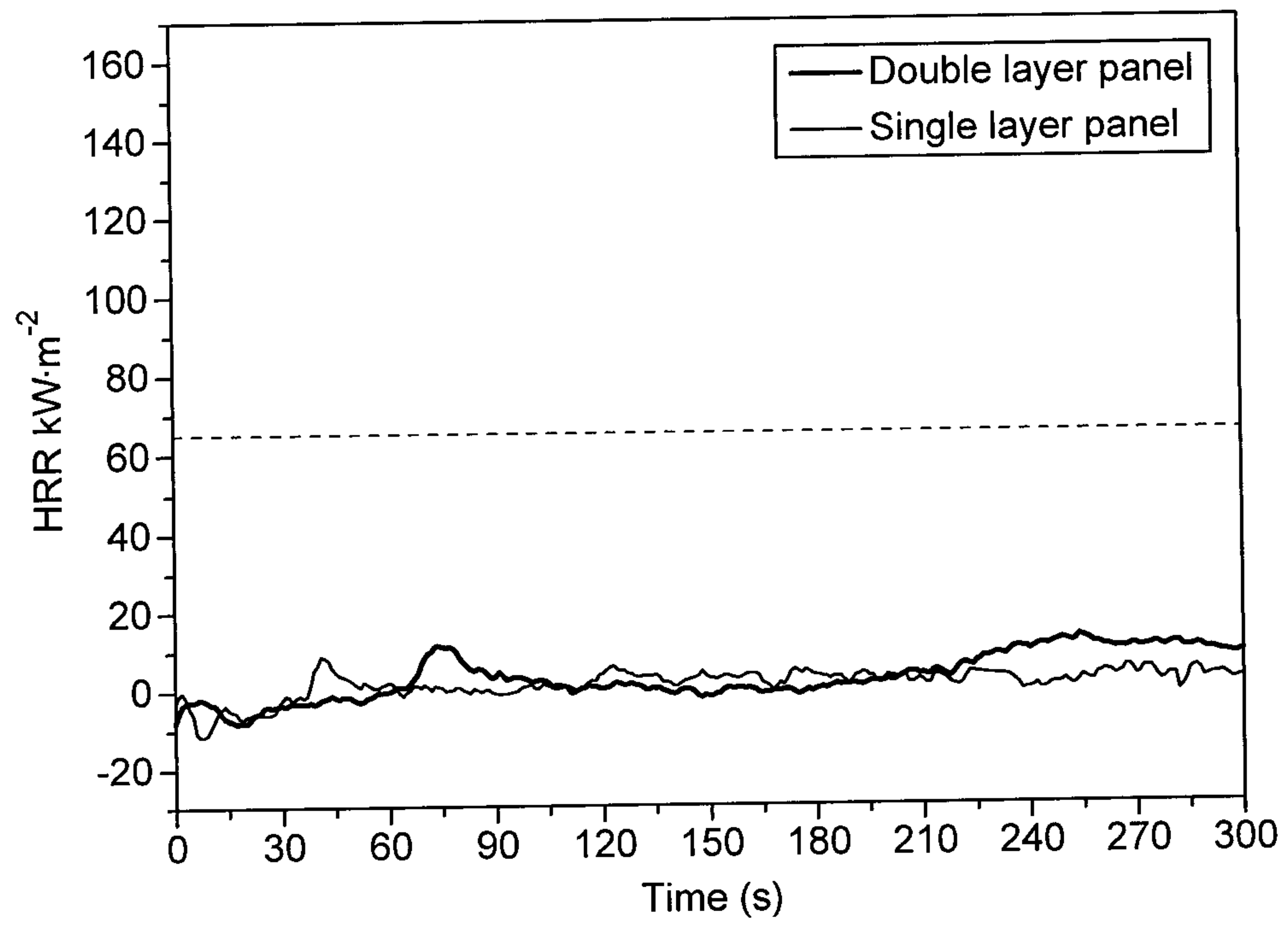
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**FIG. 13**

	P7	P8	P9	P10
Fibre:				
Initial mass of fibre (g)	25.0	24.9	25.0	12.5
Number of fibre layers	4	4	4	2
Final mass fibres + boron derivate flame retardant (g)	14.1	13.6	13.1	6.4
% wt boron derivate flame retardant	36.0	35.2	34.3	33.7
Composite:				
Resin mass (g)	73.6	73.6	73.6	36.8
Hardener mass (g)	11.0	11.0	11.0	5.5
% wt hardener	13.0	13.0	13.0	13.0
Foam weight (g)	2.3	2.3	2.3	2.3
Total mass (dry) (g)	103.8	98.7	101.0	50.2
% wt fibre (dry)	24.1	25.3	24.8	25.0
% wt boron derivate flame retardant (dry)	13.6	13.7	13.0	12.8
Maximum heat release rate (kW*m ⁻²)	17.3	14.3	16.0	9.2
Total heat release during the first 2 min (kW*min*m ⁻²)	0.2	0.4	-0.2	-1.7

FIG. 14

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**FIG. 15**

