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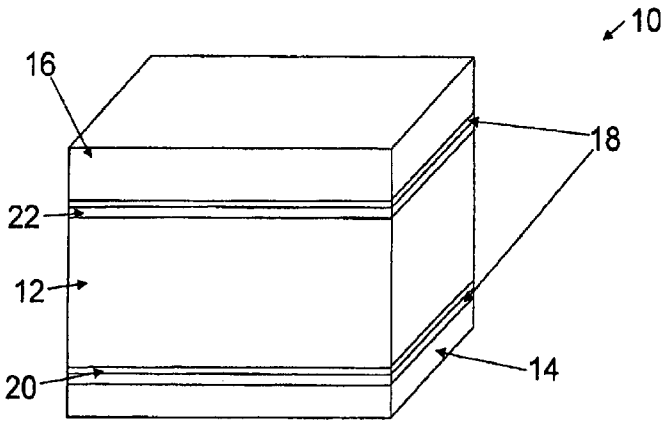
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(54) **Title:** CARBON FOAM THERMAL CORE



(57) **Abstract:** A cold storage panel (10), which includes a carbon foam core (12) having a high ratio of compressive strength to density, desirable fire retardant properties, and resistance to environmental stress. The carbon foam insulated panel (10) also includes a first layer (14) and a second layer (16) bound to a first surface and second surface of the carbon foam core (12). Applications of the carbon foam structural insulated panel include structural and fire retardant elements of residential and commercial refrigerators and freezers, food lockers, coolers, and the like.

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DESCRIPTION

CARBON FOAM THERMAL CORE

TECHNICAL FIELD

[0001] The present invention relates to the use of a carbon foam material as the core for structural panels for cold storage applications, such as commercial and residential refrigerators and freezers, food lockers, coolers, refrigerated rooms and holds, and the like. More particularly, the present invention relates to the use of carbon foam in insulated panels which provide insulation while also being non-flammable and which do not release noxious gases when exposed to flame.

BACKGROUND ART

[0002] Many cold storage panels are formed using a core material of an expanded polymeric foam like expanded polystyrene (EPS). The EPS or other foam is conventionally sandwiched between outer panels depending on the specific application. For instance, when the panel is used to form a relatively large structure such as a food locker or refrigerated room, the foam can be sandwiched between layers of oriented strand board, fiber board, plywood, or other like materials. Alternatively, the outer layers can be formed of a metal sheet, such as a thin layer of steel. When the panel is used to form a smaller structure, such as a cooler or a refrigerator or freezer, the core is sandwiched between a plastic material such as a high density polyethylene (HDPE). While this type of panel is well understood and possesses adequate insulative value, EPS and other polymeric materials are flammable when exposed to heat, are subject to chemical degradation and emit noxious gases when burned.

[0003] What is desired, therefore, is a core material for a panel for cold storage applications which possesses at least adequate insulative value (preferably a thermal R value of at least about 2, and as high as about 4 or higher), while being relatively non-flammable, resistant to chemical degradation and which does not emit noxious gases when exposed to flame. The desired core material should also be light weight, have a high strength to density ratio, can be recycled, can be used in thinner sections, is inert and

non-corrosive and resists deterioration over time. Certain carbon foams provide just such a material.

[0004] In Hardcastle et al. (U.S. Patent No. 4,425,396) an insulating panel is disclosed with a synthetic organic polymeric foam with protective weathering layers comprised of multiple thermoplastic sheets.

[0005] Cahill (U.S. Patent No. 6,656,858) describes a lightweight laminate wall comprised of a low density layer of from about 0.5 to 3 pounds per cubic foot and a second, reinforcing layer of a polymeric fabric. These structures are lightweight, have a low moisture resistance and meet building code requirements regarding transverse wind loading.

[0006] Porter (U.S. Patent No. 6,599,621) describes a structural insulated panel (SIP) with high strength and resistance to fire and particularly to water and changes in humidity. The disclosed structures are comprised of an inner insulating core with a gypsum fiberboard on one face of the insulating core and an oriented strand board on the second face of the insulating core. Preferably, the insulating core is comprised of a plastic foam such as expanded polystyrene or urethane which is bonded to both the gypsum fiberboard and the oriented strand board.

[0007] Porter (U.S. Patent No. 6,588,172) describes the incorporation of a laminated layer of plastic impregnated paper into a SIP to increase the panel's tensile strength while rendering it impervious to moisture. This layer is typically situated between the gypsum board and plastic foam core, adhered through a conventional bonding agent.

[0008] Parker (U.S. Patent No. 4,628,650) describes a SIP with a foam core with a layer having an overhang projecting from the foam core edges. The overhang is situated to facilitate an effective seal between adjacent SIPs, providing better thermal insulation. Additionally, the core of the panels has channels through the structure for the placement of joists, studs or rafters.

[0009] Clear (U.S. Patent No. 6,079,175) describes a SIP of cementitious material for building structures. A lightweight fill material such as bottom ash, cement and water is poured between spaces of two outermost ribs, which is claimed to provide insulation, strength and also

rigidity to the panel and therefore the structure the panel comprises. This SIP has the advantage of being constructed in remote or more barren areas as it is fairly inexpensive to create.

[0010] Pease (U.S. Patent No. 6,725,616) prepares an insulated concrete wall either cast or built with blocks which is attached to reinforced insulated strips. The patentee indicates that users will require less time and labor in making insulated using the patentee's method of fixing reinforced rigid foam to the surface of a concrete wall.

[0011] Pease (U.S. Patent No. 6,892,507) describes a method and apparatus for making an SIP with a rigid foam sheet. The rigid foam sheets have multiple grooves in which reinforcing strips are situated. The strips and rigid foam are then covered and bonded with a reinforcing sheet, the sheet providing both structural support and moisture retention.

DISCLOSURE OF THE INVENTION

[0012] The present invention provides a cold storage panel having a carbon foam core, which is uniquely capable of being used in applications requiring good insulative value, is non-flammable and resistant to chemical degradation and which does not emit noxious gases when exposed to flame. Moreover, since the carbon foam core material can provide adequate insulative value in thinner sheets than conventional foams, the inventive panels can be made thinner than conventional panels, thus providing significant space and cost savings.

[0013] The inventive carbon foam panel exhibits a density, compressive strength and compressive strength to density ratio to provide a combination of strength and relatively light weight characteristics not heretofore seen. In addition, the carbon lattice work of the carbon foam resists both charring and combustion while maintaining structural integrity in environmental conditions from high humidity to severely low temperatures. Furthermore, the carbon foam can be produced in a desired size and configuration and can be readily machined for a specific size for a cold storage panel.

[0014] More particularly, the inventive carbon foam cold storage panel has a carbon foam core with a density of from about 0.08 to about 0.16 grams

per cubic centimeter (g/cc) and a compressive strength of at least about 5 megaPascals (MPa), more preferably at least about 6 MPa (measured by, for instance, ASTM C695). An important characteristic for the carbon foam core when intended for use in larger scale applications such as walk-in refrigerators and freezers, food lockers, etc. is a strength to density ratio of at least about 20 MPa/g/cc, more preferably at least about 33 MPa/g/cc, most preferably at least about 37.5 MPa/g/cc, and higher.

[0015] The inventive carbon foam panel should have the carbon foam core of a relatively uniform density both longitudinally and latitudinally for consistent thermal insulation and strength characteristics throughout the panel. Specifically, the carbon foam should have a relatively uniform distribution of pores in order to provide the required high compressive strength, the pores being relatively isotropic. In addition, the carbon foam core should have a total porosity of about 65% to about 95%, more preferably about 70% to about 95% to create the optimal strength to density ratio of the carbon foam structural insulated panel.

[0016] Advantageously, to produce the carbon foam core, a polymeric foam block, particularly a phenolic foam block, is carbonized in an inert or air-excluded atmosphere, at temperatures which can range from about 500°C, more preferably at least about 800°C, up to about 3200°C to prepare the carbon foams for use in the structural carbon foam panels.

[0017] Prior to the addition of outerlayers, the carbon foam core can be treated with a variety of coatings to improve the overall performance of the carbon foam cold storage panel. For example, an anti-oxidation coating can be applied to the carbon foam to increase the longevity of the panel in highly oxidative conditions. Additionally, a fire retardant coating could also be applied to the carbon foam core to further increase the integrity of the carbon foam core and thus the panel, when exposed to extreme temperatures.

[0018] Most commonly, the carbon foam core's first and second outerfaces are each covered with a layer to form the inventive cold storage panel. Optionally, the outer layers may be comprised of oriented strand board (OSB) or a variety of gypsum board, or combinations thereof. Other

outerlayers exist including, but not limited to, a variety of thermoplastics, metals, organic sheets, fiber impregnations, and composite boards.

[0019] The carbon foam core should be bound to the outer layers to construct the cold storage panel. Binding may be through the use of materials such as adhesives or cements which create a chemical interaction between the outer layers and the carbon foam core. These include binders specific to carbon foam applications as well as general cements, mastics or high temperature glue. Optionally, mechanical materials can be used.

[0020] Alternatively, the carbon foam can be formed having a higher density, about 0.2 to about 0.6 or higher, for instance, sealed, and used as a cold storage panel without outerlayers.

[0021] An object of the invention, therefore, is a carbon foam panel having characteristics which enable it to be used in cold storage applications requiring an R value of at least about 2, and is non-flammable and resistant to chemical degradation and which does not emit noxious gases when exposed to flame.

[0022] Another object of the invention is a cold storage panel having a carbon foam core, with the structure of the carbon foam core having a sufficiently high compressive strength to be used for high stress applications.

[0023] Still another object of the invention is carbon foam panel where the carbon foam core provides a fire retardant barrier, and which is extremely resistant to both combustion and charring.

[0024] Yet another object of the invention is an insulated foam panel which can be produced in a desired size and configuration, where the carbon foam core can be machined or joined with other similar carbon foam sheets to provide larger carbon foam panels.

[0025] Another object of the invention is to provide an insulated panel which is resistant to environmental stresses including high humidity and severe temperature fluctuations.

[0026] Still another object of the invention is to provide a carbon foam insulated panel where the carbon foam core provides adequate thermal insulation to maintain a temperature differential between the one side of the

panel and the opposing side of the panel.

[0027] These aspects and others that will become apparent to the artisan upon review of the following description can be accomplished by providing a carbon foam panel with a carbon foam core having an R value of at least about 2, more preferably as high as about 4 or higher. The foam core preferably has a ratio of compressive strength to density of at least about 20 MPa/g/cc, especially a ratio of compressive strength to density of at least about 33 MPa/g/cc, and most advantageously a ratio of at least about 37.5 MPa/g/cc. The inventive cold storage panel has a carbon foam core with a density of from about 0.08 g/cc to about 0.16 g/cc, more preferably of from about 0.11 g/cc to about 0.15 g/cc, and a compressive strength of at least about 5 MPa, more preferably at least about 6 MPa, with a porosity of between about 65% and about 95%. Furthermore the thermal conductivity of the carbon foam core is from about 0.06 W/mK to about 0.3 W/mK.

[0028] Furthermore, the carbon foam core can be produced by carbonizing a polymer foam article, especially a phenolic foam, in an inert or air-excluded atmosphere. The phenolic foam precursor for the carbon foam core should preferably have a compressive strength of at least about 100 pounds per square in (psi).

[0029] It is to be understood that both the foregoing general description and the following detailed description provide embodiments of the invention and are intended to provide an overview or framework of understanding to nature and character of the invention as it is claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] Fig. 1 is a view of a carbon foam cold storage panel in accordance with an embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

[0031] Carbon foams in accordance with the carbon foam core of the present invention are prepared from polymeric foams, such as polyurethane foams or phenolic foams, with phenolic foams being preferred. Phenolic resins are a large family of polymers and oligomers, composed of a wide variety of structures based on the reaction products of phenols with

formaldehyde. Phenolic resins are prepared by the reaction of phenol or substituted phenol with an aldehyde, especially formaldehyde, in the presence of an acidic or basic catalyst. Phenolic resin foam is a cured system composed of open and closed cells. The resins are generally aqueous resoles catalyzed by sodium hydroxide at a formaldehyde:phenol ratio which can vary, but is preferably about 2:1. Free phenol and formaldehyde content should be low, although urea may be used as a formaldehyde scavenger.

[0032] The foam is prepared by adjusting the water content of the resin and adding a surfactant (eg, an ethoxylated nonionic), a blowing agent (eg, pentane, methylene chloride, or chlorofluorocarbon), and a catalyst (eg, toluenesulfonic acid or phenolsulfonic acid). The sulfonic acid catalyzes the reaction, while the exotherm causes the blowing agent, emulsified in the resin, to evaporate and expand the foam. The surfactant controls the cell size as well as the ratio of open-to-closed cell units. Both batch and continuous processes are employed. In the continuous process, the machinery is similar to that used for continuous polyurethane foam. The properties of the foam depend mainly on density and the cell structure.

[0033] The preferred phenol is resorcinol, however, other phenols of the kind which are able to form condensation products with aldehydes can also be used. Such phenols include monohydric and polyhydric phenols, pyrocatechol, hydroquinone, alkyl substituted phenols, such as, for example, cresols or xylenols; polynuclear monohydric or polyhydric phenols, such as, for example, naphthols, p.p'-dihydrexydiphenyl dimethyl methane or hydroxyanthracenes.

[0034] The phenols used to make the foam starting material can also be used in admixture with non-phenolic compounds which are able to react with aldehydes in the same way as phenol.

[0035] The preferred aldehyde for use in the solution is formaldehyde. Other suitable aldehydes include those which will react with phenols in the same manner. These include, for example, acetaldehyde and benzaldehyde.

[0036] In general, the phenols and aldehydes which can be used in the process of the invention are those described in U.S. Patent Nos. 3,960,761

and 5,047,225, the disclosures of which are incorporated herein by reference.

[0037] Optionally, the carbon foam core of the inventive panel can be created for an increased oxidation resistance by the specific inclusion of compounds solely for improving the oxidation resistance of the carbon foam. Such solid oxidation inhibiting additives include ammonium phosphate, aluminum phosphate, zinc phosphate or boric acid. An additional characteristic of the oxidation inhibiting additives is that the additives can be added during either the resin production stage or the phenolic foam forming stage of carbon foam production. Using either method, the final carbonization of the phenolic foam results in phosphorous or boron retained within the carbon foam structure that reduces the rate of oxidation of the carbon foam. Specifically, phosphorous or boron retained in the final carbon foam product from about 0.01% to about 0.5% by weight reduces the rate of oxidation by over 50%.

[0038] Alternatively, the carbon foam product can be treated with an oxidation-inhibiting agent after the completion of the carbonization process but prior to the integration in the panel. The preferred method would be to impregnate the carbon foam with aqueous solutions of phosphorous-containing materials such as ammonium phosphate, phosphoric acid, aluminum phosphate, or zinc phosphate, followed by a heat treatment to about 500°C to simultaneously remove the water and fix the phosphorous to the carbon. Additionally, water-soluble boron compounds such as boric acid can be introduced in the above manner to create an oxidation-resistant carbon foam product.

[0039] The polymeric foam used as the starting material in the production of the carbon foam core should have an initial density which mirrors the desired final density for the carbon foam which is to be formed. In other words, the polymeric foam should have a density of about 0.08 g/cc to about 0.16 g/cc. The cell structure of the polymeric foam should be closed with a porosity of between about 65% and about 95% and a relatively high compressive strength, i.e., on the order of at least about 100 psi, and as high as about 300 psi or higher.

[0040] In order to convert the polymeric foam to carbon foam, the foam is carbonized by heating to a temperature of from about 500°C, more preferably at least about 800°C, up to about 3200°C, in an inert or air-excluded atmosphere, such as in the presence of nitrogen. The heating rate should be controlled such that the polymer foam is brought to the desired temperature over a period of several days, since the polymeric foam can shrink by as much as about 50% or more during carbonization. Care should be taken to ensure uniform heating of the polymer foam piece for effective carbonization.

[0041] By use of a polymeric foam heated in an inert or air-excluded environment, a non-graphitizing glassy carbon foam is obtained, which has the approximate density of the starting polymer foam, but a compressive strength of at least about 5 MPa and, significantly, a ratio of strength to density of at least about 20 MPa/g/cc, more preferably at least about 33 MPa/g/cc. The carbon foam has a relatively uniform distribution of isotropic pores having, on average, an aspect ratio of between about 1.0 and about 1.5.

[0042] Referring now to Fig 1, there is revealed a partial side view of a cold storage panel 10 with a carbon foam core 12 in accordance with one of the embodiments of the present invention.

[0043] Carbon foam core 12 and panel 10 are generally planar, though can be constructed to meet a variety of specifications. Optionally, carbon foam core 12 can be curved or possess rounded edges through either machining or molding to best fit the desired cold storage application.

[0044] Cold storage panel 10 includes both the first outer layer 14 and second outer layer 16 situated on the opposite outer surfaces of carbon foam core 12. As with carbon foam core 12 and panel 10, both the first outer layer 14 and the second outer layer 16 can possess a variety of shapes for the desired application. The first outer layer 14 and the second outer layer 16 can comprise similar or completely different materials depending upon the specific structural application of the panel. These materials include typical construction materials such as plywood, oriented strand board, drywall, gypsum, cement composites, wood composites, or a variety of other rigid

organic or inorganic construction boards. Furthermore, first outer layer 14 and second outer layer 16 can also be impregnations of the above materials or include thermoplastics, resins, carbon composites, ceramic composites or a variety of other artificially created materials. In certain cases these layers can include thin metal skins around carbon foam core 12, or outer layer 14 and outer layer 16 can include hardened metal composites. Obviously, the selection of first outer layer 14 and the second outer layer 16 will be based on the necessary tensile strength and fire retardant and insulative properties of the specific panel 10. Furthermore, first outer layer 14 and second outer layer 16 can be of two different materials where the use of panel 10 necessitates such properties. Other materials which can comprise either one or both of the outer layers 14 and 16 include but are not limited to the following: paper, reinforced paper composites, oriented strand board, fiberboard, drywall, gypsum, gypsum composites, wood, wood composites, plywood, thermoplastics, plastic composites, resins, metals, metal alloys, metal composites, and combinations thereof.

[0045] In an additional embodiment, sheets of compressed particles of exfoliated graphite are incorporated into the panel, situated in contact with the carbon foam core. These graphite sheets can either be on one side or both sides of the carbon foam core, in between the outer layers and the carbon foam core. Suitable sheets of compressed particles of exfoliated graphite (often referred to in the industry as "flexible graphite") can be produced by intercalating graphite flakes with a solution containing, e.g., a mixture of nitric and sulfuric acids, expanding or exfoliating the flakes by exposure to heat, and then compressing the exfoliated flakes to form coherent sheets. The production of sheets of compressed particles of exfoliated graphite is described in, for instance, U.S. Patent Application Publication No. US-2005-0079355-A1, the disclosure of which is incorporated herein by reference.

[0046] By the incorporation of sheets of compressed particles of exfoliated graphite with the carbon foam core, a superior fire retardant structure is created. The anisotropic thermal properties of an compressed exfoliated graphite sheet on one or both opposing sides of the carbon foam

core provide significant improvements in thermal management.

[0047] The first outer layer 14 and the second outer layer 16 are connected to the carbon foam core 12 through a bonding or adhesive material 18. This bonding or adhesive material 18 can include chemical bonding agents suitable for specific applications ranging from high temperature conditions to exposure to an acidic environment. Different chemical bonding materials include adhesives, glues, cement, and mastic. Optionally, the first outer layer 14 and second outer layer 16 can be attached to the carbon foam core 12 through mechanical materials. While this method does affect the integrity and uniform characteristics of carbon foam core 12, mechanical connects are available for little cost and are extremely quick to complete. Various mechanical attaching methods of attaching both the first outer layer 14 and the second outer layer 16 to the carbon foam core 12 include but are not limited to nails, studs, screws, braces, struts, fasteners, staples, and combinations thereof. Additionally, the first outer layer 14 and the second outer layer 16 can be compressedly bound to the carbon foam core through a series of high compression treatments of the outer layers 14 and 16 to the carbon foam core. While less permanent than either the mechanical or chemical attachment options, this attach type introduces no extra chemical compounds or weakens the structural integrity of carbon foam core 12 as does either the chemical or mechanical attachment methods.

[0048] First coating 20 and second coating 22 are both optional and applied to carbon foam core 12 to alter the carbon foam core's 12 properties. Specifically, first coating 20 and second coating 22 can be identical or different, depending upon the conditions and necessary properties of the carbon foam core 12. For example, first coating 20 and second coating 22 can both be a coating to improve the fire retardant properties of the carbon foam core 12. Additionally, the first coating 20 could be an oxidation resistant coating where as the second coating 22 could be a fire retardant coating where one side of panel 10 would be more likely exposed to an oxidation atmosphere while the other side of panel 10 would have a greater likelihood of being exposed to fire. Also, first coating 20 and second coating 22 are

optionally applied; for many applications of cold storage panel 10, neither first coating 20 nor second coating 22 are necessary.

[0049] With carbon foam core 12 as the insulating layer in cold storage panel 10, panel 10 has an inherent fire retardant/resistant property. As other insulating materials merely preclude oxygen from the structural insulating panel's structure, carbon foam core 12 is extremely resistant to both combustion or charring. Specifically, carbon foam core 12 is mainly linked carbons with relatively few other elements present within its foam structure. As such, little exists for combustion, other than the simple oxidation of the carbon of carbon foam core 12. For this oxidation to occur, temperatures have to reach rather extreme temperatures, making carbon foam core 12 very suitable for applications where fire retardant structures are required.

[0050] Similarly, carbon foam core 12 is resistant to many environmental stresses including insects, humidity, and heat. Carbon foam is an extremely hard substance, lending itself poorly to insect habitation while its chemical and structural properties are virtually not altered by a change in humidity. Furthermore, first outer layer 14 and second outer layer 16 can be selected for the specific environmental applications to which panel 10 will be subjected.

[0051] Finally, cold storage panel 10 and its fire retardant nature, superior strength to density ratio as well as resistance to chemical degradation make panel 10 suitable for a wide variety of cold storage applications. These abovementioned applications are feasible uses of the inventive carbon foam structural insulated panel yet by no mean include all applications for which this invention is feasible.

[0052] Accordingly, by the practice of the present invention, cold storage panels with carbon foam cores, having heretofore unrecognized characteristics are prepared. These panels with carbon foam cores exhibit exceptionally high compressive strength to density ratios, much improved fire retardance and environmental stability, making them uniquely effective at cold storage applications, ranging from refrigerators and freezers, to food

lockers and coolers.

[0053] The disclosures of all cited patents and publications referred to in this application are incorporated herein by reference.

[0054] The above description is intended to enable the person skilled in the art to practice the invention. It is not intended to detail all of the possible variations and modifications that will become apparent to the skilled worker upon reading the description. It is intended, however, that all such modifications and variations be included within the scope of the invention that is defined by the following claims. The claims are intended to cover the indicated elements and steps in any arrangement or sequence that is effective to meet the objectives intended for the invention, unless the context specifically indicates the contrary.

CLAIMS

What is claimed is:

1. A cold storage panel comprising a carbon foam material with a density of from about 0.08 g/cc to about 0.16 g/cc.

2. The panel of claim 1 further comprising:
a first outer layer bound to a first surface of the carbon foam material; and
a second outer layer bound to a second surface of the carbon foam material.

3. The panel of claim 1 wherein the carbon foam material has a ratio of compressive strength to density of at least about 20 MPa/g/cc.

4. The panel of claim 1 wherein the carbon foam material has a thermal conductivity of from about 0.06 W/mK to about 0.3 W/mK.

5. The panel of claim 1 wherein the carbon foam material includes a coating on the carbon foam's exterior surface.

6. The panel of claim 5 wherein the coating improves fire retardancy of the carbon foam material.

7. The panel of claim 6 wherein the coating improves oxidation resistance of the carbon foam material.

8. The panel of claim 1 further comprising a layer of compressed particles of exfoliated graphite on at least one surface of the carbon foam material.

9. The panel of claim 2 wherein the outer layers are selected from the group consisting of paper, reinforced paper composites, oriented strand board, fiberboard, drywall, gypsum, gypsum composites, wood, wood composites, plywood, thermoplastics, plastic composites, resins, metals, metal alloys, metal composites, and combinations thereof.

10. A cold storage panel comprising a carbon foam material having a ratio of compressive strength to density of at least about 20 MPa/g/cc.

11. The panel of claim 10 further comprising:
a first outer layer bound to a first surface of the carbon foam material; and
a second outer layer bound to a second surface of the carbon foam material.

12. The panel of claim 10 wherein the carbon foam material with a density of from about 0.08 g/cc to about 0.16 g/cc.

13. The panel of claim 10 wherein the carbon foam material has a thermal conductivity of from about 0.06 W/mK to about 0.3 W/mK.

14. The panel of claim 10 wherein the carbon foam material includes a coating on the carbon foam's exterior surface.

15. The panel of claim 14 wherein the coating improves fire retardancy of the carbon foam material.

16. The panel of claim 14 wherein the coating improves oxidation resistance of the carbon foam material.

17. The panel of claim 10 further comprising a layer of compressed particles of exfoliated graphite on at least one surface of the carbon foam material.

18. The panel of claim 11 wherein the outer layers are selected from the group consisting of paper, reinforced paper composites, oriented strand board, fiberboard, drywall, gypsum, gypsum composites, wood, wood composites, plywood, thermoplastics, plastic composites, resins, metals, metal alloys, metal composites, and combinations thereof.

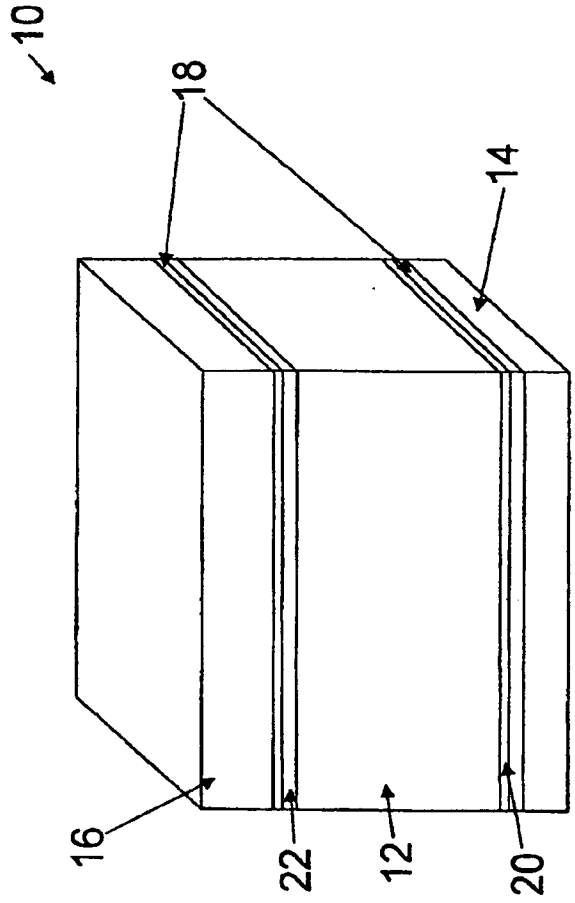


FIG. 1