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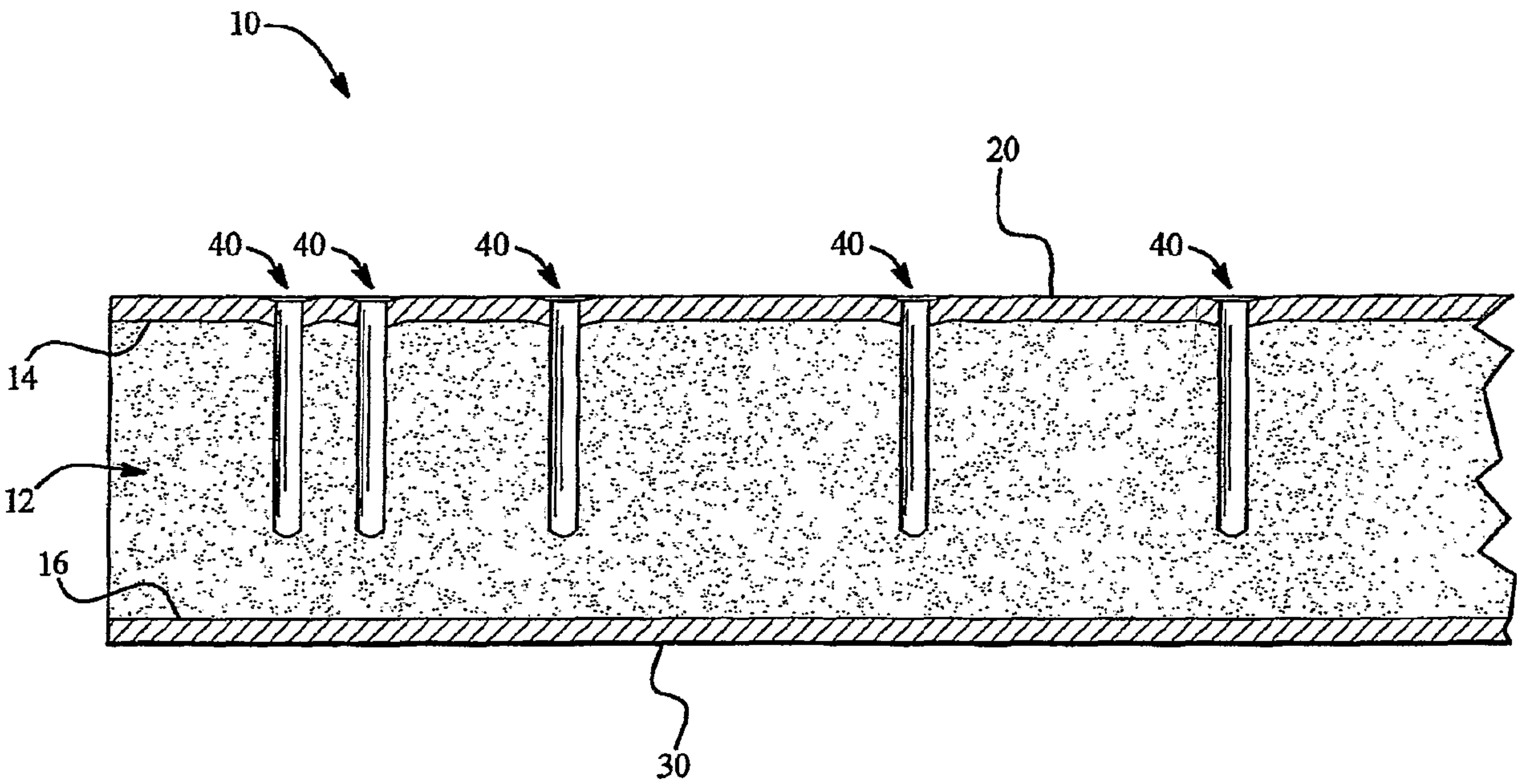

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Low density acoustical gypsum boards having a perforated cover sheet that have good sound absorption properties and are generally clear of falling gypsum dust. The invention optionally provides a cover sheet having a pattern producing a textured visual effect particularly when viewed from a distance. The acoustical gypsum boards can be produced on modified existing gypsum board lines.

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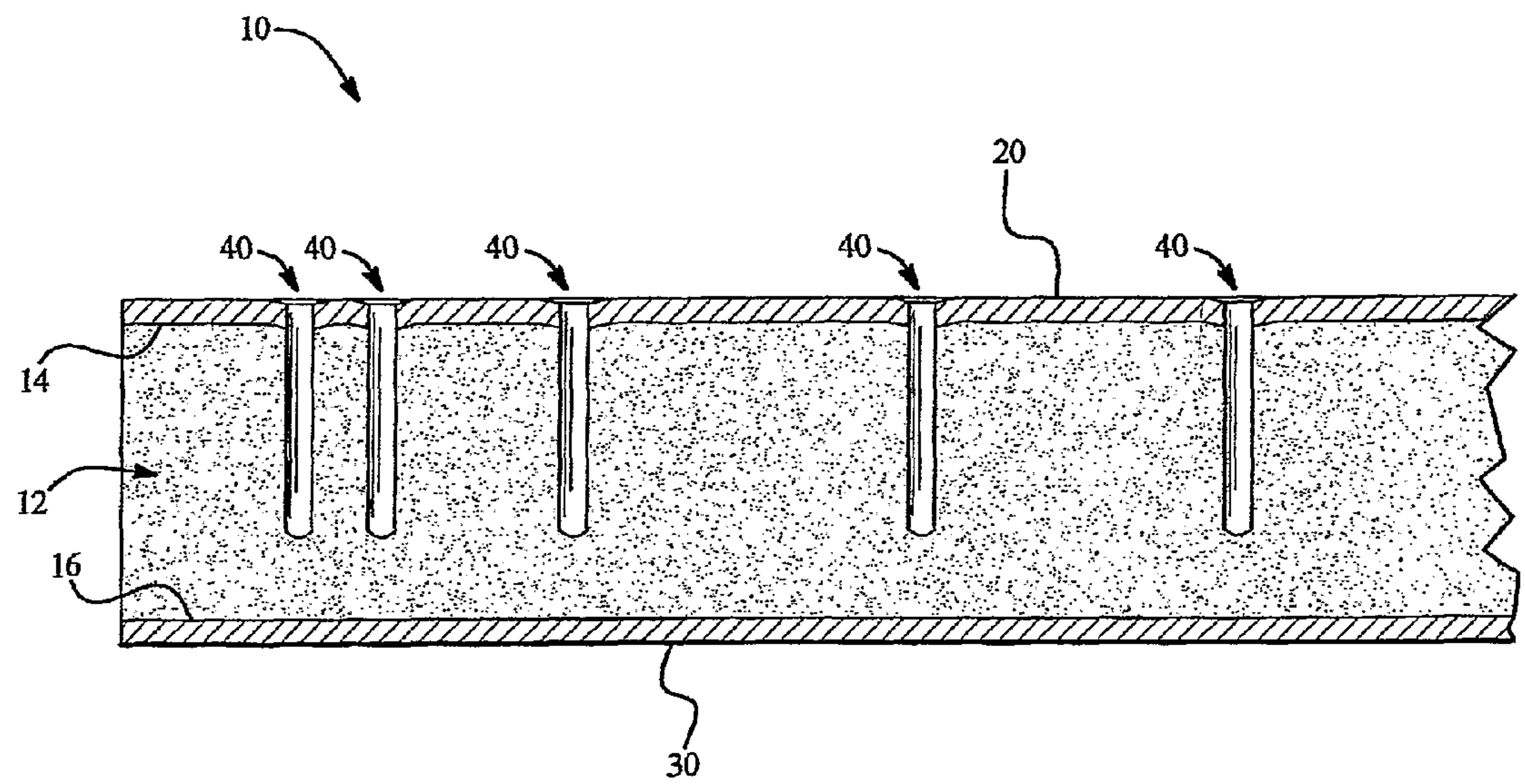

(57) Abstract: Low density acoustical gypsum boards having a perforated cover sheet that have good sound absorption properties and are generally clear of falling gypsum dust. The invention optionally provides a cover sheet having a pattern producing a textured visual effect particularly when viewed from a distance. The acoustical gypsum boards can be produced on modified existing gypsum board lines.

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ACOUSTICAL GYPSUM BOARD FOR CEILING PANEL

FIELD OF THE INVENTION

The present invention relates to a lightweight gypsum board suitable for use as a soundproofing or acoustical panel. The invention provides economical and convenient-to-use low density acoustical gypsum boards having sound absorbing characteristics on a par with conventional acoustic panels and a method for their preparation.

BACKGROUND OF THE INVENTION

Acoustical panels are used to form soundproofing interior surfaces. They typically come in the form of ceiling panels, wall panels, and partitions (e.g., partitions between office cubicles), and are used in commercial buildings, residential buildings, public buildings, auditoriums, etc. The panels are generally planar and include acoustical characteristics derived from the materials selected for their manufacture and from their ability to accept sound absorbing perforation without adversely affecting their durability.

Most common acoustical panels are mineral wool-based, and may also include fiberglass, expanded perlite, paper fiber, and binders such as starch. Mineral wool is the most prevalent and important ingredient in such prior acoustical panels. Mineral wool-based acoustical panels are very porous which accounts for their good sound absorption. Fillers, such as expanded perlite, may be incorporated into mineral wool-based acoustic panels to reduce the weight of the final product. In addition, mineral wool-based acoustical panels are commonly perforated in order to further increase their sound absorption.

Currently, acoustical panels are prepared in a manner similar to those used in conventional papermaking processes by water-felting dilute aqueous dispersions of mineral wool, perlite, binder, and other ingredients as desired. In such processes, the dispersions flow onto a moving foraminous support wire, such as that of a Fourdrinier or Oliver mat-forming machine for dewatering, as will be appreciated by one of ordinary skill in the art. The dispersions are dewatered first by gravity drainage and then by vacuum suction. The resulting dewatered but yet wet mat is dried in a convection oven, the dried material is cut to desired dimensions, and multiple coatings are applied to obtain the finished panel.

Acoustical panels also can be made by a wet pulp molding or cast process such as described in U.S. Pat. No. 1,769,519. In accordance with this process, a molding composition comprising granulated mineral wool fibers, fillers, colorants, a binder such as cooked starch, and water, is prepared for molding or casting the panel. The composition is placed upon suitable trays that have been covered with paper or a paper-backed metallic foil and then the composition is screeded to a desired thickness with a forming plate. A decorative surface, such as a surface with random elongated fissures, also may be provided by a screed bar or patterned roll. The trays filled with the mineral wool composition are then placed in an oven to dry.

Both water felting and tray casting techniques for preparing acoustical panels are not entirely satisfactory because of their complexity and expense. In addition to raw material costs, these processes require large amounts of water and energy. Furthermore, panels prepared according to these methods may be subject to sagging, especially if the panels are stored under conditions of high humidity or when the panels are installed horizontally on widely spaced supporting members. The tendency to sag is aggravated by the presence of hygroscopic binders such as recycled paper fiber or starch. In addition, several surface coatings are generally required in order to achieve a proper appearance in the final acoustical panel, due to the absorbency of the materials used. Furthermore, where the panels are perforated care must be taken not to cover or clog the perforated holes with the final coatings. For example, after perforation, coatings must be applied by spraying rather than simpler, less expensive roller-applied coating processes to avoid clogging of the perforated holes.

Conventional gypsum wallboard, which comprises set gypsum (calcium sulfate dihydrate), sandwiched between paper cover sheets, is commonly used in construction applications because of its durability, fire resistant characteristics and economy. However, such paper covered gypsum wallboard has not in the past been considered for use in acoustical ceiling panels for a number of reasons. First, such gypsum wallboard does not inherently have good sound absorption properties. Even if it is punched or perforated in the same manner as conventional mineral wool-based acoustical panel, little or no significant sound absorption improvement is achieved. Furthermore, punching conventional paper covered gypsum wallboard causes substantial amounts of gypsum dust to loosen and fall from the perforated holes. (Conventional acoustical panels also can exhibit some dust (powder) loss.) Also, conventional gypsum wallboard may be heavy, *ca.* 40 lbs/ ft^3 ("pcf"), and this weight makes conventional wallboard unsuitable in most acoustical applications. Even the recently developed lightweight gypsum board described in U.S. Patent No. 5,922,447 to the present inventor, Mirza A. Baig, typically has a density greater than or equal to about 21 pcf, which exceeds the typical densities of conventional mineral wool based acoustical panels of about 12 – 20 pcf. Therefore, the problems of lack of sound absorption, high density, and gypsum dust loss have discouraged the use of either conventional or lightweight face-sheeted gypsum board in acoustic tile applications.

One type of tray cast gypsum-based acoustical panel is discussed in U.S. Patent Application Publication 2004/0231916A1 to Englert et al. This application is primarily directed to panels that, unlike conventional wallboard preferably have no top face paper layer. In a less preferred embodiment of Englert et al. a top face paper is used but there is no suggestion to perforate after drying, which is not surprising because perforating this dried board would be expected to produce substantial dust loss.

The prior art conventional gypsum wallboard is flat and smooth, having no significant visual surface texture. Known acoustical panels, on the other hand, typically have a substantial three-dimensional texture. If a way could be found to produce acoustical gypsum boards that achieve the same visual effect (and sound absorption properties) as are found in conventional mineral-wool based acoustical panels without actually adding texture and thereby damaging the outer surface of the face paper of the boards, this would be yet another useful contribution to the art.

Therefore, it would be advantageous if a way could be found to make conventionally produced gypsum wallboard type products of sufficiently low density and sufficiently good sound absorbing properties to be useful in acoustical applications. It would be particularly advantageous if a way could be found to make such gypsum wallboard type products having acceptable sound absorption properties that are not subject to the problem of falling gypsum dust, that achieve the same visual effect as known textured acoustical panels, and that also have resistance to sag equal to or better than conventional mineral wool-based ceiling panels.

BRIEF SUMMARY OF THE INVENTION

The present invention comprises low density acoustical gypsum boards, having top and bottom cover sheets, that are relatively inexpensive to manufacture, and that can be produced efficiently in large quantities on an existing gypsum board line. These low density acoustical gypsum boards resist permanent deformation, such as sag, and have sound absorption properties on a par with conventional acoustical panels. The low density acoustical gypsum boards are perforated and are not subject to the problem of falling gypsum dust. Furthermore, the invention optionally provides a top cover sheet to which a visual pattern has been applied in order to make the surface appear to be textured, particularly when viewed from a distance (i.e. when viewed by a person standing on the floor of a room looking up at the ceiling).

In a broad aspect, the present invention relates to a gypsum-based acoustical board having a set gypsum core disposed between a face paper and a back paper comprising: a set gypsum core made from a core formulation having about 75% to about 90% by weight stucco based on the total weight of the core formulation, about 0 to about 15% by weight perlite based on the total weight of the core formulation, about 2% to about 12% by weight paper fiber based on the total weight of the core formulation, and about 0.5% to about 5% by weight starch based on the total weight of the core formulation; and a multiplicity of sound-absorbing perforations extending through the face paper and into but not through the set gypsum core.

In another broad aspect, the present invention relates to a method of making gypsum-based acoustical board, comprising the steps of: (a) mixing a slurry of water, stucco in an amount from about 75% to about 90% by weight based on the total solids weight, perlite in an amount up to about 15% by weight based on the total solids weight, paper fiber in an amount from about 2% to about 12% by weight based on the total solids weight, and a starch in an amount from about 0.5% to about 5% by weight based on the total solids weight; (b) adding a soap foam having a density of about 10 pcf to the slurry; (c) depositing the slurry on a first cover sheet; (d) maintaining the slurry under conditions sufficient for the stucco to form a set gypsum core; (e) placing a second cover sheet over the set gypsum core to form an acoustical board; (f) drying the formed board; (g) cutting the dried board; and (h) perforating one of the cover sheets of the dried board in such a manner that the perforations extend into but not through the set gypsum core.

In another broad aspect, the present invention relates to a method of making gypsum-based acoustical board, comprising the steps of: (a) mixing a slurry comprising water, stucco in an amount from about 75% to about 90% by weight based on the total solids weight, perlite in an amount up to about 15% by weight based on the total solids weight, paper fiber in an amount from about 2% to about 12% by weight based on the total solids weight, and a starch in an amount from about 0.5% to about 5% by weight based on the total solids weight; (b) adding a soap foam having a density of about 10 pcf to the slurry; (c) depositing the slurry on a first cover sheet; (d) maintaining the slurry under conditions sufficient for the stucco to form a set gypsum core; (e) placing a second cover sheet over the set gypsum core to form an acoustical board; (f) drying the formed board to constant weight to produce a dried board having a density of not more than about 20 pcf; (g) cutting the dried board; and (h) perforating one of the cover sheets of the dried board using pins with a pin count of about 1800 pins per square foot and a pin diameter of about 0.062 inch, in such a manner that the perforations extend into but not through the set gypsum core.

These and other advantages of the present invention, as well as additional inventive features, will be apparent from the description of the invention provided herein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of a cut-away end view of a low density acoustical gypsum board in accordance with the invention including top and bottom cover sheets, a set gypsum core, and perforations extending across the top cover sheet and into the set gypsum core;

FIG. 2 is a plan view of a top cover sheet (face paper) having a pattern as printed on the face paper cover sheet used in one embodiment of the present invention; and

FIG. 3 is a plan view of the top cover sheet of the low density acoustical gypsum board of FIG. 1 showing the printed pattern of FIG. 2 and including small circular puncture holes extending through the face paper and into the set gypsum core.

DETAILED DESCRIPTION OF THE INVENTION

In one embodiment of the invention, low density acoustical gypsum boards of this invention include a set gypsum core structure made using a core formulation including calcium sulfate hemihydrate ("stucco"), perlite, paper fiber, and starch. The set gypsum core of the low density acoustical gypsum boards is sandwiched between two substantially parallel top and bottom cover sheets, such as paper cover sheets, to provide substantially flat, planar, top and bottom surfaces. In addition, the low density acoustical gypsum boards include perforations formed through the top (outer) surface of the board that extend through the cover sheet and into the set gypsum core. In a preferred embodiment, the perforations are generally well-formed small circular holes that extend generally perpendicularly to the top outer surface of the board through the top cover sheet and into the set gypsum core. In another preferred embodiment, the exposed surface of the perforated top cover sheet is printed with a pattern. The low density acoustical gypsum boards are manufactured generally in the same fashion as conventional wallboard, modified as discussed below.

Preferably, the low density acoustical gypsum board of the present invention exhibits a Noise Reduction Coefficient (NRC) of at least about 0.5, according to ASTM C 423-02, and more preferably, a Noise Reduction Coefficient at or near 1.0. In some embodiments, the low density acoustical gypsum board demonstrates a Noise Reduction Coefficient according to ASTM C 423-02 of at least about 0.55 up to a yet more preferable NRC of at least about 0.7.

Now turning to Figure 1, there is provided a low density acoustical gypsum board 10 according to one embodiment of the present invention. The acoustical gypsum board 10 includes a set gypsum core 12 having a top surface 14 and a bottom surface 16. The set gypsum core 12 is formed between a face cover sheet 20 and a back cover sheet 30 with the cover sheets (20, 30) bonded to the core. A multiplicity of perforations 40 extend through the face cover sheet 20 and the top surface 14 into the set gypsum core 12.

Figure 2 illustrates an exemplary pattern 50 according to one embodiment of the present invention that is applied to the outer surface of a face cover sheet 20a. In this example, the pattern creates a visual appearance of texture to the human eye when viewed from a sufficient distance or perspective, for example by a person standing on the floor of a room looking up at the ceiling.

Figure 3 is a plan view of the low density acoustical gypsum board 10 of Figure 1 covered on its top surface by the pattern-bearing face cover sheet 20a of Figure 2 and including a multiplicity of perforations 40 formed through face cover sheet 20a and into set gypsum core 12.

Set gypsum core 12 is made from an aqueous slurry of the key core components listed below in Table 1. Other conventional ingredients that may be added to the slurry, such as dispersants, strength additives (e.g. metaphosphates), and accelerators, are described generally below.

TABLE 1. CORE FORMULATION RANGES

Component	Amount in weight %	Preferred amount in weight %[1]
Stucco	75 - 90	80 - 85
Perlite	0 - 15	5 - 8
Paper (cellulose	2.0 - 12	6 - 10
Starch	0.5 – 5.0	0.5 - 2
Water / solids ratio	2.0 – 3.5	2.3 – 2.5

[1] This embodiment of the core formulation is based on 100% solids of these four key ingredients.

The acoustical gypsum board of the present invention has a board density of not more than about 20 pcf. In a preferred embodiment, the acoustical gypsum board of the present invention has a board density of about 17 to about 19 pcf, and most preferably the acoustical gypsum board of the present invention will have a board density of not more than about 16 pcf.

It is preferred that perlite be used in the core formulations (to help lower board density), although in a less preferred embodiment, the core formulation can be free of perlite. The presence of perlite in the core formulation, however, reduces estimated Noise Reduction Coefficient (NRC) values of the final acoustical gypsum boards. Paper fiber, on the other hand, can also be used in core formulations to achieve yet lower board density while at the same time providing increased NRC values, offsetting the detrimental loss of noise reduction caused by the perlite. Therefore, in preferred embodiments, as discussed below, rising perlite levels are balanced with increased levels of paper fiber.

In a preferred embodiment, perlite will be used in an amount of at least about 5% by weight of the core formulation. Additionally in this preferred embodiment, both perlite and paper fiber must be present in the core formulation, and the weight ratio of perlite to paper fiber will range from about 1:1.1 to about 1:2. In a yet more preferred embodiment, the weight ratio of perlite to paper fiber will range from about 1:1.4 to about 1:1.6.

For example, in one embodiment, the core formulation comprises, based on the total weight of the core formulation:

stucco	85% by weight;
perlite	5% by weight;
paper fiber	8% by weight; and
starch	2% by weight.

The weight ratio of perlite to paper fiber is 1:1.6. By incorporating a soap foam (discussed below) having a foam density of 10 pcf (over and above the 100% solids weight % total of the core formulation itself), this core formulation can be used to make an acoustical gypsum board having a density as low as about 17.0 pcf. Other additives can be included over and above the 100% solids weight % total of the core formulation itself (*i.e.* accelerators, dispersants, and strength additives as discussed below).

The low density acoustical gypsum boards of the present invention must be perforated to produce a multiplicity of perforations that are substantially clear of gypsum dust or powder. That such clear perforations can be achieved is quite unexpected given that when conventional gypsum boards are perforated in the same manner, a substantial amount of gypsum dust is released. The perforations in boards of the present invention are illustrated, for example, in Figures 1 and 3. As shown there, the acoustical gypsum board is perforated through the face paper to produce holes extending into the set gypsum core, but not passing through the back paper. The orientation of the holes is, as shown, preferably generally perpendicular to the planar surface of the first cover sheet, or face paper. Thus, in a key aspect, the overall set gypsum core provides sound absorption properties in the low density acoustical gypsum boards when combined with perforations substantially clear of gypsum dust.

The low density acoustical gypsum boards may be punched using a perforation pin count (100% sharp pins) of about 1800 pins per square foot, pin diameter 0.062 in. Other pin counts and pin diameters can be used, as will be recognized by those skilled in the art. For example, a pin count of about 1850 per square foot, of about 1750 per square foot, or of about 1566 per square foot could be used, and pin diameters of about 0.050 in. and about 0.045 in. could be used. Also, any type of pin may be used, including sharp, blunt, or combinations thereof. It will be appreciated by one skilled in the art that pin count can be varied, and pin type, style, and diameter can be varied, or used in various combinations, in order to achieve the desired sound reduction properties. The depth of the perforated holes can range from about ¼ inch to about ½ inch.

The boards can be made, and punched, according to a batch process or in a continuous process. The punching, or perforation step, can be applied as part of a standard commercial wallboard production line, following the drying of the paper-covered board product.

Cover sheets 20 and 30 may be made of paper as in conventional gypsum wallboard, although other useful cover sheet materials known in the art may be used. Paper cover sheets provide strength characteristics in the acoustical gypsum board. Useful cover sheet paper includes Manila 7-ply™ and News-Line 7-ply™, available from United States Gypsum Corporation, Chicago, Illinois; and Grey-Back 3-ply™ and Manila Ivory 3-ply™, available from Caraustar, Newport, Indiana. The paper cover sheets comprise top cover sheets, or face paper, and bottom cover sheets, or back paper. A preferred back cover sheet paper is News-Line. A preferred face cover sheet paper is Manila 7-ply™.

Gypsum-based products have the tendency to sag under conditions of high humidity. The proper choice of back paper helps reduce sag in the finished acoustical gypsum board. A preferred back paper for this purpose in the low density acoustical gypsum boards of the present invention is News-Line 7-ply. In addition, strength additives such as sodium trimetaphosphate, may be added to the core formulations to further reduce sag. Also, a formaldehyde-based coating can be applied to the back paper of the acoustical gypsum boards to further reduce sag.

The face paper can be used plain, or with a pattern applied to it, as discussed above and shown in Figure 2. Many variations of pattern and pattern color may be used on the face paper. Tinted papers can also be used as appropriate, and color printing or inks can be employed to apply the pattern. The pattern as shown in Figure 2, as well as other patterns, can be made by taking a photo of a given design and printing the design on the face paper. Also, printing of the face paper can be done on-line during the production process, preferably after the face paper is dried. In addition, after printing the pattern, a protective coating can be applied on the outer surface of the face paper to protect the printed pattern from abrasion and environmental conditions.

A soap foam is required in making the low density acoustical gypsum boards of the present invention, in order to reduce the density of the final board. The soap foam density can range from about 5.0 pcf to about 12.0 pcf; a preferred soap foam density is about 10 pcf, to achieve a final board density of not more than about 20 pcf. The soap foam is used in an amount over and above the 100% solids weight % total of the core formulation itself. For example, a soap can be used in an amount of about 2 g to about 3 g per about 1000 g total solids (or about 0.2% to about 0.3% by weight based on total solids) when used to make the soap foam and added to the core formulation as in Table 1 over and above the 100% solids weight % total of the core formulation itself. Useful soaps for making the soap foam include FA 403 - Agent X-2332™ available from Stepan Chemical Company, Northfield, Illinois.

The bond between a set gypsum core and the paper cover sheets may be adversely affected by the presence of foam in the core formulation. Since approximately 1/3 of the gypsum boards by volume may consist of foam, the foam can interfere with the bond between the set gypsum core and the paper cover sheets. Thus, a non-foamed bonding layer may be provided on the set gypsum core-contacting surfaces of both the face paper and the back paper prior to forming the gypsum boards. This layer formulation is commonly the same as the core formulation, except that the foam is omitted. In order to form this layer, foam can be mechanically removed from the core formulation, or a different foam-free formulation can be applied at the set gypsum/ face paper interface.

The primary component of the core formulation is calcium sulfate hemihydrate or calcined gypsum, also referred to as stucco. The calcined gypsum can be in the form of alpha calcium sulfate hemihydrate, beta calcium sulfate hemihydrate, water-soluble calcium sulfate anhydrite, or mixtures thereof. In preferred embodiments, the calcined gypsum is in the form of beta calcium sulfate hemihydrate. A useful calcined gypsum is CKS dry stucco, available from United States Gypsum Corp., Chicago, Illinois. The calcined gypsum is present in an aqueous slurry of the core formulation in an amount sufficient to allow for the formation of an interlocking matrix of set gypsum in the final paper-covered board. In the core formulation used to make the set gypsum core, stucco is present in an amount ranging from about 75% to about 90% by weight based on the total (solids) weight of the core formulation; preferably, the stucco is present in an amount ranging from about 80% to about 85% by weight based on the total weight of the core formulation.

As noted earlier, it is preferred that perlite is used in the core formulation. In the core formulation used to make the set gypsum core, perlite can be present in an amount up to about 15% by weight based on the total (solids) weight of the core formulation;

preferably, perlite is present in an amount ranging from about 5% to about 8% by weight based on the total weight of the core formulation.

In the practice of the invention, the perlite density must be in the range of about 3 to about 8.5 pcf. The perlite can be obtained from a number of commercial sources. In the examples described below, Type 3-S™ brand perlite available from Silbrico located in Hodgkins, Illinois, was used. This perlite typically has a density of about 3 to about 5.0 pcf.

Perlite is a form of glassy rock similar to obsidian. It generally contains 65-75% SiO_2, 10-20% Al_2O_3, 2-5% H_2O, and smaller amounts of soda, potash, and lime. When perlite is heated to its softening point, it expands to form a light fluffy material similar to pumice. In preparing the perlite for use in the present invention it is first ground to a size finer than minus 200 mesh. The ground perlite is then heated to a temperature of about 1500 °-1800 °F, and preferably about 1750 °F. This process is carried out in a perlite expander by first heating the air and then introducing the finely ground perlite into the heated air. As it is carried by the air, it is heated and pops like popcorn to form expanded perlite. Expanded perlite contains many fine cracks and fissures, and, when placed in contact with water, the water penetrates the cracks and fissures and enters into the air filled cavities of the perlite, thereby greatly increasing the weight of the particles.

For the purposes of the present low density acoustical panel, it is important that the perlite not be coated or treated in any way which will make the individual perlite particles watertight or even water resistant. If so, the water resistant coating or treatment will result in non-uniform distribution of the perlite in the aqueous slurry of the core formulation, and it will also be more difficult, if not impossible, for the gypsum crystals to penetrate and interlock with the perlite particles.

Paper fiber must be used in the core formulation. A useful form of paper fiber is hydropulp newsprint or hydropulped waste paper. Other cellulosic fibrous materials can be used, alone or in combination with hydropulped paper fiber, such as wood fiber or dry fiberized gypsum wallboard paper or Kraft paper. In the core formulation used to make the set gypsum core, paper fiber is present in an amount ranging from about 2% to about 12% by weight based on the total (solids) weight of the core formulation; preferably, paper fiber is present in an amount ranging from about 6% to about 10% by weight based on the total weight of the core formulation.

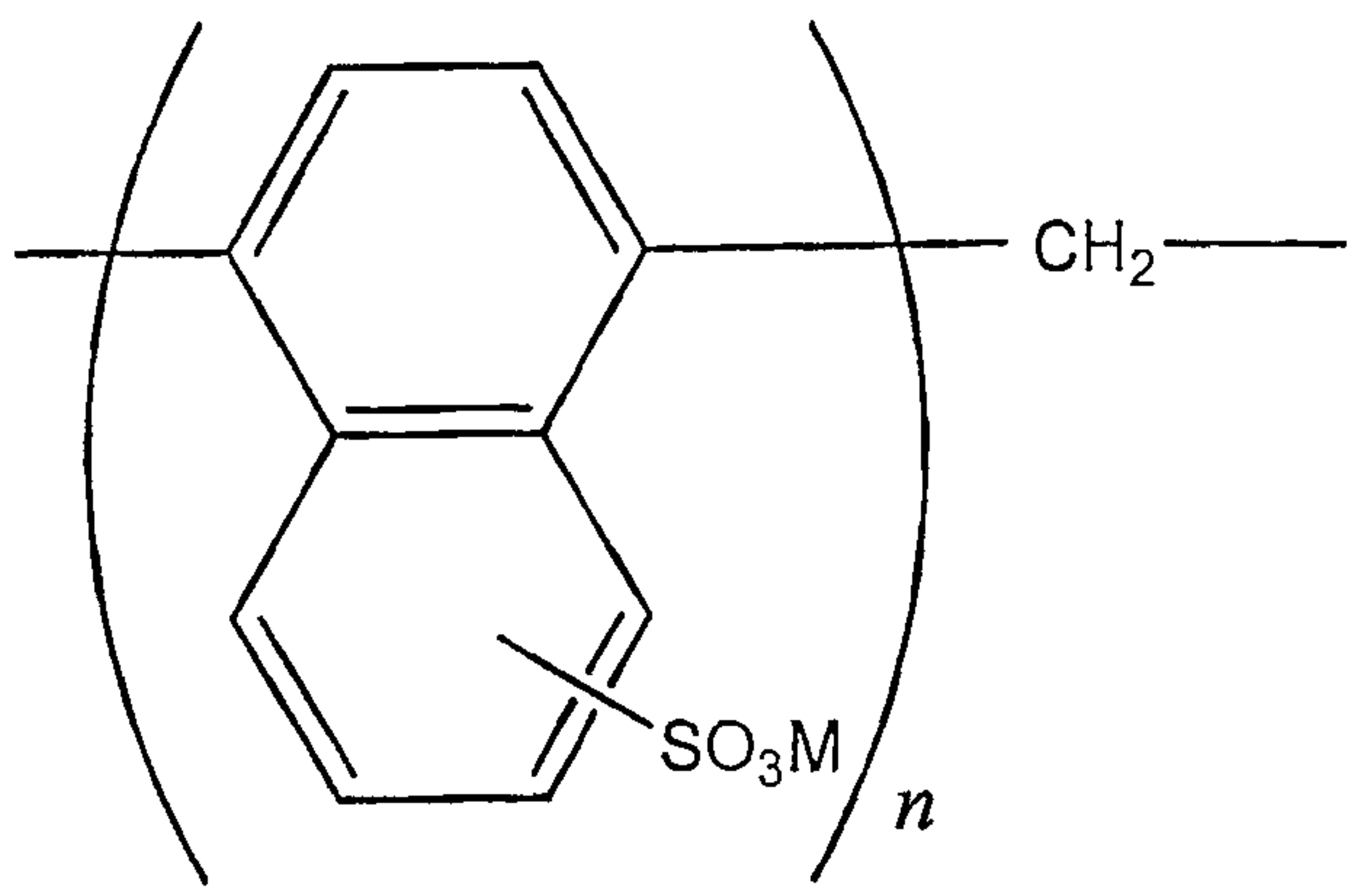
Starch must be used in the core formulation. For example, wheat starch can be used. In another embodiment, pearl starch can be used, which is a known combination of starch made from corn, potato, and/or wheat stock. The starch may be provided in raw form or partially or fully cooked separately prior to mixing with the core formulation. Partial cooking in the present process is considered to occur once the starch and water slurry temperature reaches 150 °F. The starch is considered to be fully cooked once the starch slurry reaches a temperature of at least 185 °F. Through partial or full cooking, pearl starch is converted from being migrating in nature to being non-migrating in nature. When non-migrating, the starch is retained in the core portion of the board prior to setting. The presence of the starch in the core also aids in the binding of the face paper to the core. Alternate sources of starch which are also contemplated are acid-modified starches including Gypset made by Ogilive, located in Montreal, Canada, and LC-211™, a common starch made from flour, supplied by Archer Daniels Midland of Dodge City, Kansas. In the latter two cases, the starches are of the migrating type. Another useful starch is acid-modified corn flour, available as HI-BOND™ from Bunge, St. Louis, Missouri. This starch has the following typical analysis: moisture 10.0%, oil 1.4%, solubles 17.0%, alkaline fluidity 98.0%, loose bulk density 30 lb/ft^3, and a 20% slurry producing a pH of 4.3. Pregelatinized starch in particular, can be used in slurries prepared in accordance with the core formulations as in Table 1. A preferred pregelatinized starch is pregelatinized corn starch, for example pregelatinized corn flour available from Bunge, St. Louis, Missouri, having the following typical analysis: moisture 7.5%, protein 8.0%, oil 0.5%, crude fiber 0.5%, ash 0.3%; having a green strength of 0.48 psi; and having a loose bulk density of 35.0 lb/ft^3. In the core formulation used to make the set gypsum core, starch is present in an amount ranging from about 0.5% to about 5% by weight based on the total (solids) weight of the core formulation; preferably, starch is present in an amount ranging from about 0.5% to about 2% by weight based on the total weight of the core formulation.

Accelerators can be added to the core formulations of the present invention, for example, wet gypsum accelerator (WGA), as described in U.S. Patent No. 6,409,825 to Yu et al. One desirable heat resistant accelerator (HRA) can be made from the dry grinding of landplaster (calcium sulfate dihydrate). Small amounts of additives (normally about 5% by weight) such as sugar, dextrose, boric acid, and starch can be used to make this HRA. Sugar or dextrose are currently preferred. Another useful accelerator is "climate stabilized accelerator" or "climate stable accelerator," (CSA) as described in U.S. Patent No. 3,573,947. For example, an accelerator (HRA or CSA) can be used in an amount of about 5 g / 1000 g total solids (or about 0.5% by weight based on total solids) when added to the core formulation as in Table 1 over and above the 100% solids weight % total of the core formulation itself.

Dispersants can be added to the core formulations of the present invention. Useful dispersants include polynaphthalenesulfonates and BOREM™, available from Boremco Laboratories, River Falls, Massachusetts. For example, a dispersant can be used in an amount of about 0.9 g / 1000 g total solids (or about 0.1% by weight based on total solids) when added to the core formulation as in Table 1 over and above the 100% solids weight % total of the core formulation itself.

The naphthalenesulfonate dispersants that may be used in the present invention include polynaphthalenesulfonic acid and its salts(polynaphthalenesulfonates) and derivatives, which are condensation products of naphthalenesulfonic acids and formaldehyde. Particularly desirable polynaphthalenesulfonates include sodium and calcium naphthalenesulfonate. The average molecular weight of the naphthalenesulfonates can range from about 3,000 to 20,000, although it is preferred that the molecular weight be about 8,000 to 10,000. A higher molecular weight dispersant has higher viscosity, and generates a higher water demand in the formulation. Useful naphthalenesulfonates include LOMAR D™, available from Henkel Corporation, DILOFLO™, available from GEO Specialty Chemicals, Cleveland, Ohio, and DAXAD™, available from Hampshire Chemical Corp., Lexington, Massachusetts. It is preferred that the naphthalenesulfonates be used in the form of an aqueous solution, for example, in the range of about 40-45% by weight solids content.

Useful polynaphthalenesulfonates have the general structure (I):



(I)

wherein n is >2, and wherein M is sodium, potassium, calcium, and the like.

For example, a polynaphthalenesulfoante dispersant can be used in an amount of about 0.9 g / 1000 g total solids (or about 0.1% by weight based on total solids) when added to the core formulation as in Table 1 over and above the 100% solids weight % total of the core formulation itself.

Strength additives can be added to the core formulations of the present invention, for example, metaphosphates such as sodium trimetaphosphate. Any suitable water-soluble metaphosphate or polyphosphate can be used in accordance with the present invention. It is preferred that a trimetaphosphate salt be used, including double salts, that is trimetaphosphate salts having two cations. Particularly useful trimetaphosphate salts include sodium trimetaphosphate, potassium trimetaphosphate, calcium trimetaphosphate, sodium calcium trimetaphosphate, lithium trimetaphosphate, ammonium trimetaphosphate, and the like, or combinations thereof. A preferred trimetaphosphate salt is sodium trimetaphosphate. It is preferred to use the trimetaphosphate salt as an aqueous solution, for example, in the range of about 10-15% by weight solids content. Other cyclic or acyclic polyphosphates can also be used, as described in U.S. Patent No. 6,409,825 to Yu et al. For example, sodium trimetaphosphate can be used in an amount of about 0.9 g / 1000 g total solids (or about

0.1% by weight based on total solids) when added to the core formulation as in Table 1 over and above the 100% solids weight % total of the core formulation itself.

As shown in the following examples, low density acoustical gypsum panels were prepared using the core formulations of Table 1. Except where indicated, Manila 7-ply paper, either plain or with an applied pattern, was used as the top cover sheet or face sheet. A non-foamed bonding layer (as described above) was applied to the set gypsum core-contacting surfaces of both the back paper and the face paper. The average thickness of the panels was 0.54 inch. In addition, each acoustical gypsum board was perforated through the face sheet. The perforation depth was ½ inch (except as indicated), and the perforation pin count (100% sharp pins) was 1800 pins per square foot, pin diameter 0.062 in.

In the following examples, certain additives were included in the core formulation as in Table 1 over and above the 100% solids weight % total of the core formulation itself. The following additive levels were included in all of the examples: accelerator (HRA or CSA) at 0.5% by weight based on total solids; dispersant at 0.1% by weight based on total solids; and sodium trimetaphosphate at 0.1% by weight based on total solids. Additionally, in each example below (except as indicated), soap foam at a density of 10 pcf was incorporated into the core formulations.

EXAMPLE 1A

Preparation of Low density acoustical gypsum board

Sample low density acoustical gypsum boards were prepared by a casting process in accordance with U.S. Patent No. 5,922,447 using the core formulations of Table 1 with a high density soap foam (e.g. 10 pcf) incorporated into slurry of the core formulation.

EXAMPLE 1 B

Preparation of Low density acoustical gypsum board by a continuous process

Sample low density acoustical gypsum boards were prepared by a continuous process in accordance with U.S. Patent Nos. 6,342,284 to Yu et al. and 6,632,550 to Yu et al. This includes the separate generation of a high density foam (e.g. 10 pcf) and introduction of the foam into the slurry of the other ingredients as described in Example 5 of these patents.

EXAMPLE 2

Low density acoustical gypsum board - assessment of paper fibers and high density foam

Step 1. The following core formulations were prepared as an aqueous slurry as shown in Table 2.

TABLE 2

Slurry formula: Component \	Board Formula 1 (weight % solids)	Board Formula 2 (weight % solids)	Board Formula 3 (weight % solids)	Board Formula 4 (weight % solids)
Stucco	85.6	85.6	85.6	85.6
Perlite	5.0	5.0	5.0	5.0
Dry paper fiber	7.4	3.7	1.9	0
Wet paper fiber	0	3.7	5.6	7.4
Total paper fiber	7.4	7.4	7.4	7.4
Starch	2.0	2.0	2.0	2.0
Water / solids ratio	2.5	2.7	2.4	2.7

Dry paper fiber: fiberized gypsum wallboard paper

Wet paper fiber: hydropulped waste paper

Additives were included in addition to the above total solids: accelerator (HRA or CSA) at 0.5% by weight based on total solids; dispersant at 0.1% by weight based on total solids; and sodium trimetaphosphate at 0.1% by weight based on total solids.

Soap foam for each formulation sample was prepared as follows. Soap (2.0 g), available as product FA 403 – Agent X-2332 from Stepan Chemical Company, Northfield, Illinois, was mixed with water (148 g) in a high shear Hamilton Beach blender for 10 seconds. The resulting foam volume was 900 ml; the foam density was 10 pounds per cubic foot. This soap foam was incorporated into the core formulations of Table 2.

Step 2. Sample boards were prepared by casting as in Example 1A using the core formulations of Table 2, and perforated, as discussed above. The perforation depth was ½ inch, and the perforation pin count (100% sharp pins) was 1800 pins per square foot, pin diameter 0.062 in.

TABLE 3

Properties	**Board 1**	**Board 2**	**Board 3**	**Board 4**
Thickness, inch	0.545	0.545	0.545	0.545
Density, pcf	17.5	16.7	18.0	17.5
Weight, lb/MSF	795	758	818	795
Water evaporation, lb/MSF	1519	1519	1475	1486
Estimated NRC	0.61	0.55	0.54	--
Dust, g/MSF	768	182	192	240

"MSF" is a standard abbreviation in the art for a thousand square feet.

As shown in Table 3, the sample boards have densities lower than 20 pcf and acceptable NRC values. Also, in Boards 2-4 dust was significantly reduced.

EXAMPLE 3

Low density acoustical gypsum board – assessment of paper cover sheets, paper fibers and high density foam.

The following core formulation was used to make the aqueous slurry (solids by weight %):

stucco	86.5%
perlite	5.0%
paper fiber (hydropulp)	6.5%
pregelatinized corn starch	2.0%.

As in Example 2, a soap foam having a foam density of 10 pcf was used. Additional additives were included in addition to the above total solids: CSA at 0.5% by weight based on total solids; Borem at 0.1% by weight based on total solids; and sodium trimetaphosphate at 0.1% by weight based on total solids. The sample boards were cast, and perforated, as in Step 2 of Example 2. The perforation depth was ½ inch, and the perforation pin count (100% sharp pins) was 1800 pins per square foot, pin diameter 0.062 in.

TABLE 4

Components	**Board 5**	**Board 6**	**Board 7**	**Board 8**
Face paper	7-ply Manila	7-ply Manila	3-ply Manila/Ivory	3-ply Manila/Ivory
Back paper	7-ply News-line	7-ply News-line	7-ply News-line	7-ply News-line
Water / solids ratio	2.3	2.4	2.3	2.4
Properties				
Thickness, inch	0.555	0.555	0.555	0.555
Density, pcf	19.0	17.3	17.8	17.2
Weight, lb/MSF	879	800	823	796
Water evaporation, lb/MSF	1596	1526	1543	1526
Estimated NRC	0.45	0.55	0.44	0.46
Dust, g/MSF	173	134	160	200

As shown in Table 4, the sample boards have densities lower than 20 pcf, and no significant difference was observed in NRC values using 7-ply or 3-ply sheets on the top surface of the board. However, reduction of the paper fiber level reduced NRC values. Dust levels were acceptable in comparison to conventional acoustical panel (300 g/MSF), as discussed above.

EXAMPLE 4

Low density acoustical gypsum board – assessment of printed paper cover sheets and high density foam

Step 1. The following core formulations were prepared as an aqueous slurry as shown in Table 5.

TABLE 5

Slurry formula: Component \	Board Formula 9 (weight % solids)	Board Formula 10 (weight % solids)	Board Formula 11 (weight % solids)	Board Formula 12 (weight % solids)
Stucco	85.0	84.2	85.0	84.0
Perlite	5.0	4.9	5.0	5.0
Paper fiber (hydropulp)	8.0	8.0	8.0	8.0
Starch	2.0	3.0	2.0	3.0
Foam[1] density, pcf	10.0	10.0	10.0	10.0
Water / solids ratio	2.4	2.4	2.4	2.4
Face paper	Manila	Manila	Manila – printed w/ pattern of Fig. 2	Manila – printed w/ pattern of Fig. 2

Additives were included in addition to the above total solids: accelerator (HRA or CSA) at 0.5% by weight based on total solids; dispersant at 0.1% by weight based on total solids; and sodium trimetaphosphate at 0.1% by weight based on total solids.

[1] Soap foam prepared as in Ex. 2

Step 2. Sample boards were prepared by casting as in Step 2 of Example 2, using the core formulations of Table 5, and perforated, as discussed above. The perforation depth was ½ inch, and the perforation pin count (100% sharp pins) was 1800 pins per square foot, pin diameter 0.062 in.

TABLE 6

Properties	Board 9	Board 10	Board 11	Board 12
Set time, min.	11.0	11.0	11.0	11.0
Thickness, inch	0.550	0.550	0.550	0.550
Density, pcf	18.1	17.4	17.8	18.2
Weight, lb/MSF	830	798	816	834
Water evaporation, lb/MSF	1570	1695	1496	1568
Estimated NRC	0.58	0.52	0.53	0.55

As shown in Table 6, the sample boards have densities lower than 20 pcf and acceptable NRC values. No negative impact was observed on NRC values using either plain or printed face paper.

EXAMPLE 5

Low density acoustical gypsum board – assessment of 3-ply and 7-ply printed paper cover sheets and high density foam

Step 1. The following core formulations were prepared as an aqueous slurry as shown in Table 7.

TABLE 7

Slurry formula: Component \	Board Formula 13 (wt % solids)	Board Formula 14 (wt % solids)	Board Formula 15 (wt % solids)	Board Formula 16 (wt % solids)	Board Formula 17 (wt % solids)
Stucco	85.0	84.0	85.0	84.0	84.0
Perlite	5.0	5.0	5.0	5.0	5.0
Paper fiber (hydropulp)	8.0	8.0	8.0	8.0	8.0
Starch	2.0	3.0	2.0	3.0	3.0
Foam density, pcf	10.0[1]	10.0[1]	10.0[1]	10.0[1]	10.0[2]
Water / solids ratio	2.4	2.4	2.4	2.4	2.4
Face paper	Manila 3-ply – printed w/ pattern of Fig. 2	Manila 3-ply – printed w/ pattern of Fig. 2	Manila 7-ply – printed w/ pattern of Fig. 2 and coated	Manila 7-ply – printed w/ pattern of Fig. 2 and coated	Manila 7-ply

Additives were included in addition to the above total solids: accelerator (HRA or CSA) at 0.5% by weight based on total solids; dispersant at 0.1% by weight based on total solids; and sodium trimetaphosphate at 0.1% by weight based on total solids.

[1] Soap foam prepared as in Ex. 2

[2] Higher amount of soap foam - prepared as in Ex. 2 using 3.0 g soap and 222 g water

Step 2. Sample boards were prepared by casting as in Step 2 of Example 2, using the core formulations of Table 7, and perforated, as discussed above. The perforation depth was ½ inch, and the perforation pin count (100% sharp pins) was 1800 pins per square foot, pin diameter 0.062 in.

TABLE 8

Properties	Board 13	Board 14	Board 15	Board 16	Board 17
Set time, min.	11.0	11.0	11.0	11.0	
Thickness, inch	0.555	0.555	0.555	0.555	0.555
Density, pcf	16.4	17.2	18.0	18.1	15.9
Weight, lb/MSF	759	796	833	837	735
Water evaporation, lb/MSF	1354	1467	1477	1496	1388
Estimated NRC	0.53	0.55	0.54	0.53	0.59

As shown in Table 8, the sample boards have densities lower than 20 pcf and acceptable NRC values. For boards 13-16, no negative impact was observed on NRC values using either 3-ply printed paper or 7-ply printed and coated paper. For board 17, an increased amount of high density soap foam produced lower board density and increased the NRC value.

EXAMPLE 6

Low density acoustical gypsum board – assessment of printed paper cover sheets, paper fibers, perlite, and high density foam

Step 1. The following core formulations were prepared as an aqueous slurry as shown in Table 9.

TABLE 9

Slurry formula: Component \	Board Formula 17 (weight % solids)	Board Formula 18 (weight % solids)
Stucco	81.9	80.0
Perlite	7.0	7.0
Paper fiber (hydropulp)	8.1	10.0
Starch	3.0	3.0

Foam[1] density, pcf	10.0	10.0
Water / solids ratio	2.5	2.5
Face paper	Manila – printed w/ pattern of Fig. 2	Manila – printed w/ pattern of Fig. 2

Additives were included in addition to the above total solids: accelerator (HRA or CSA) at 0.5% by weight based on total solids; dispersant at 0.1% by weight based on total solids; and sodium trimetaphosphate at 0.1% by weight based on total solids.

[1] Soap foam prepared as in Ex. 2

Step 2. Sample boards were prepared by casting as in Step 2 of Example 2, using the core formulations of Table 9, and perforated, as discussed above. The perforation depth was ½ inch, and the perforation pin count (100% sharp pins) was 1800 pins per square foot, pin diameter 0.062 in.

TABLE 10

Properties	Board 18	Board 19
Set time, min.	12.0	13.0
Thickness, inch	0.545	0.545
Density, pcf	16.9	17.2
Weight, lb/MSF	765	782
Water evaporation, lb/MSF	1550	1508
Estimated NRC	0.61	0.53

As shown in Table 10, the sample boards have densities lower than 20 pcf and acceptable NRC values.

EXAMPLE 7

Low density acoustical gypsum board – assessment of paper cover sheets including a non-foamed bonding layer applied to the set gypsum core-contacting surfaces

Two sets of three boards each were prepared using the following core formulation to make the slurry (solids by weight %):

stucco	84.5%
perlite	5.0%
paper fiber (hydropulp)	7.5%
pregelatinized corn starch	3.0%.

A soap foam having a foam density of 5.0 pcf was used. Additional additives were included in addition to the above total solids: CSA at 0.5% by weight based on total solids; Borem at 0.1% by weight based on total solids; and sodium trimetaphosphate at 0.1% by weight based on total solids. The water/solids ratio was 2.4:1. The first set (Set A) of sample boards was cast, and perforated (except at 0.375 in. depth), as in Step 2 of Example 2. For the second set (Set B) of sample boards, prior to casting, a non-foamed bonding layer (prepared from the same core formulation without foam) was manually applied to the set gypsum core-contacting surfaces of both the back paper and the face paper using a 4.0 inch wide brush, then the second set (Set B) of sample boards was cast, and perforated (except at 0.375 in. depth), as in Step 2 of Example 2. The set time was approx. 11.0 min. for all boards cast. In the following Table 11, the results are presented as average values.

TABLE 11

Properties	**Set A**	**Set B**
Thickness, inch	0.545	0.545
Density, pcf	21.7	22.0
Water evaporation, lb/MSF	1787	1668
Estimated NRC	0.46	0.48

The boards of Set B possessed an excellent bond to the paper cover sheets and to the set gypsum core after the board was dried. As shown in Table 11, the bond between the set gypsum core and the paper cover sheets was significantly improved, without adversely affecting estimated NRC after perforation of the face paper. The presence of the non-foamed bonding layer provided a better bond between the paper cover sheets and the set gypsum core in the low density acoustical gypsum boards of the present invention, with no adverse effect on estimated NRC values after perforation of the top surface cover sheet (face paper). The lower estimated NRC values in both sets of boards (Sets A and B) were due to the lower perforation depth.

EXAMPLE 8

Resistance to permanent deformation – assessment of low density acoustical gypsum board sag resistance

The low density acoustical gypsum boards made according to Examples 3 - 6 demonstrated resistance to permanent deformation such as sag. Sag was tested in 2 X 4 foot board samples as follows. 3 inch wide X 24 inch long strips of board were cut from the aforementioned samples and tested under 104°F/95% R.H. conditions. The board strips were laid in a horizontal position on two ¼ inch wide supports, attached to a support frame, whose length extended the full 3 inch width of the board, with one support at each end of the board. The 3 inch wide ends in contact with the support frame were weighted down against the supports or clamped to the supports. The board strips remained in this position for a specified period of time (in this example, 3 days) under continuous surrounding conditions of 104 °F and 95% relative humidity. The extent of sag of the board (sag deflection) was then determined by measuring the distance in inches of the center of the top surface of the board from the imaginary horizontal plane extending between the top edges of the ends of the board, *i.e.*, a plane corresponding to the surface of the board before exposure to the test conditions. After a 3 day test period, sag deflection for the test strips was measured in the range 0.122 – 0.218 inch, which is substantially superior to known conventional ceiling panels, in which sag deflection is normally 0.3 – 0.5 inch under the same test conditions.

The low density acoustical gypsum boards made according to Examples 3 - 6 passed the indicative flame spread test and met the Class-A rating.

The low density acoustical gypsum boards made according to Examples 3 - 6 were tested for MOR strength (psi). The average MOR strength achieved was about 200 psi, or greater.

The low density acoustical gypsum boards made according to Examples 3 - 6 were less friable than conventional acoustical panels. Cutability, including edge detail, of these low density acoustical gypsum boards was good using a mechanical cutting saw. Edge detail, namely a lip, was introduced by grinding.

The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. It should be understood that the illustrated embodiments are exemplary only, and should not be taken as limiting the scope of the invention.

What is Claimed is:

1. A gypsum-based acoustical board having a set gypsum core disposed between a face paper and a back paper comprising:

a set gypsum core made from a core formulation having about 75% to about 90% by weight stucco based on the total weight of the core formulation, about 0 to about 15% by weight perlite based on the total weight of the core formulation, about 2% to about 12% by weight paper fiber based on the total weight of the core formulation, and about 0.5% to about 5% by weight starch based on the total weight of the core formulation; and

a multiplicity of sound-absorbing perforations extending through the face paper and into but not through the set gypsum core.

2. The acoustical board of claim 1, wherein the core formulation includes stucco in an amount from about 80% to about 85% by weight based on the weight of the core formulation, perlite in an amount from about 5% to about 8% by weight based on the weight of the core formulation, paper fiber in an amount from about 6% to about 10% by weight based on the weight of the core formulation, and starch in an amount from about 0.5% to about 2% by weight based on the weight of the core formulation.

3. The acoustical board of claim 1, wherein the perlite has a density of from about 3.0 pcf to about 5.0 pcf.

4. The acoustical board of claim 1 , wherein the paper fiber is hydropulp.

5. The acoustical board of claim 1 , wherein the starch is pregelatinized corn starch.

6. The acoustical board of claim 1, wherein the face paper has a pattern that creates a visual appearance of a texture when viewed from a distance.

7. The acoustical board of claim 1, wherein the perforations have a diameter of about 0.062 inch and are present at about 1800 pins per square foot.

8. The acoustical board of claim 1, wherein the board is about 0.54 inch thick and the perforations are from about ¼ inch to about ½ inch deep.

9. The acoustical board of claim 1, wherein the board density is from about 16 pcf to about 20 pcf.

10. The acoustical board of claim 1, wherein the board density is from about 16 pcf to about 17 pcf.

11. The acoustical board of claim 1, having an NRC value from about 0.50 to about 0.65.

12. The acoustical board of claim 1, wherein the perlite in the core formulation is present at a weight ratio of perlite to paper fiber of about 1:1.1 to about 1:2.

13. The acoustical board of claim 1, wherein the perlite in the core formulation is present at a weight ratio of perlite to paper fiber of about 1:1.4 to about 1:1.6.

14. A method of making gypsum-based acoustical board, comprising the steps of:

(a) mixing a slurry of water, stucco in an amount from about 75% to about 90% by weight based on the total solids weight, perlite in an amount up to about 15% by weight based on the total solids weight, paper fiber in an amount from about 2% to about 12% by weight based on the total solids weight, and a starch in an amount from about 0.5% to about 5% by weight based on the total solids weight;

(b) adding a soap foam having a density of about 10 pcf to the slurry;

(c) depositing the slurry on a first cover sheet;

(d) maintaining the slurry under conditions sufficient for the stucco to form a set gypsum core;

(e) placing a second cover sheet over the set gypsum core to form an acoustical board;

(f) drying the formed board;

(g) cutting the dried board; and

(h) perforating one of the cover sheets of the dried board in such a manner that the perforations extend into but not through the set gypsum core.

15. The method of claim 14, further comprising applying a pattern on the second cover sheet prior to step (g).

16. A method of making gypsum-based acoustical board, comprising the steps of:

(a) mixing a slurry comprising water, stucco in an amount from about 75% to about 90% by weight based on the total solids weight, perlite in an amount up to about 15% by weight based on the total solids weight, paper fiber in an amount from about 2% to about 12% by weight based on the total solids weight, and a starch in an amount from about 0.5% to about 5% by weight based on the total solids weight;

(b) adding a soap foam having a density of about 10 pcf to the slurry;

(c) depositing the slurry on a first cover sheet;

(d) maintaining the slurry under conditions sufficient for the stucco to form a set gypsum core;

(e) placing a second cover sheet over the set gypsum core to form an acoustical board;

(f) drying the formed board to constant weight to produce a dried board having a density of not more than about 20 pcf;

(g) cutting the dried board; and

(h) perforating one of the cover sheets of the dried board using pins with a pin count of about 1800 pins per square foot and a pin diameter of about 0.062 inch, in such a manner that the perforations extend into but not through the set gypsum core.

17. The method of claim 16, further comprising applying a pattern on the second cover sheet prior to step (g).

FIG. 1

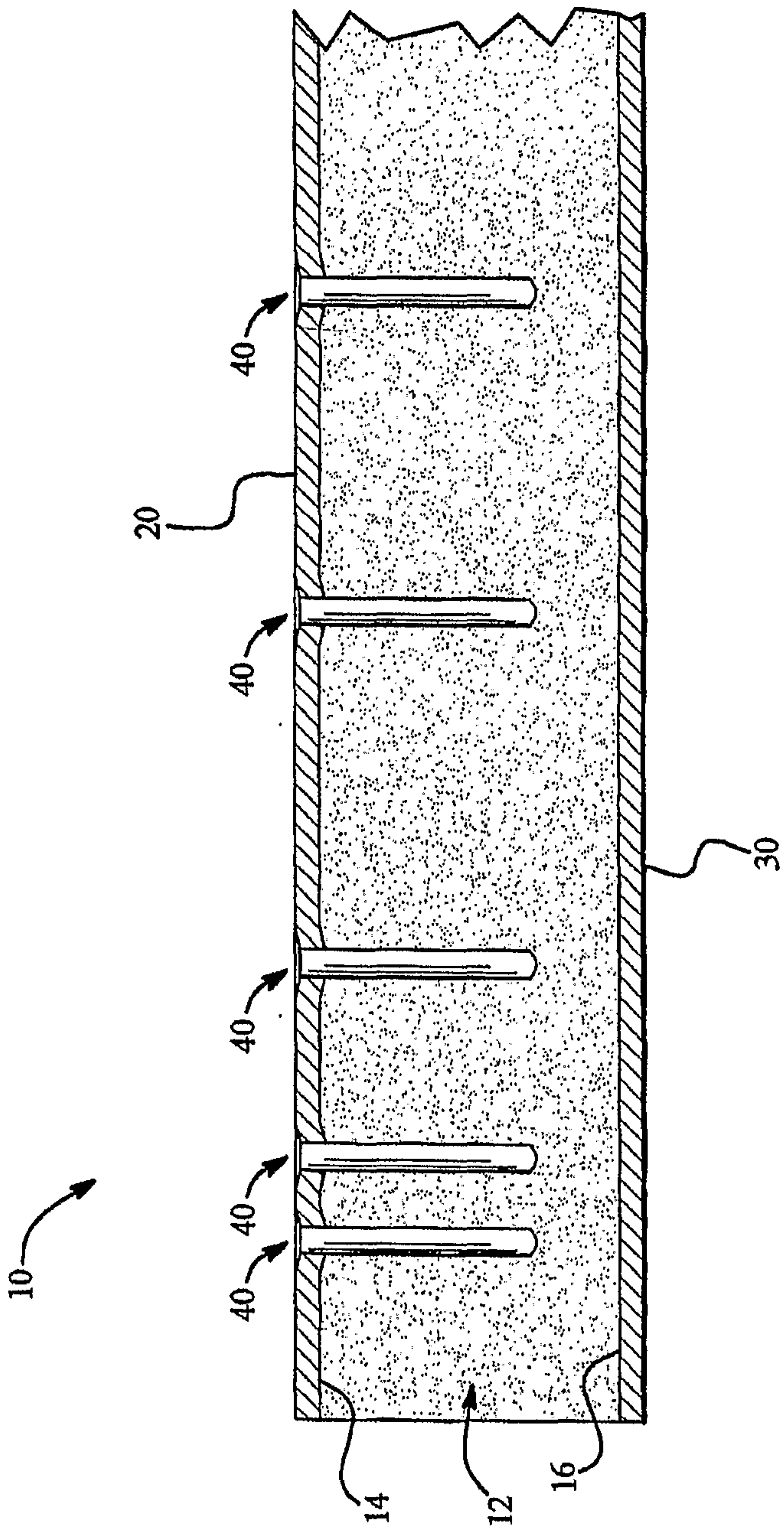


FIG. 2

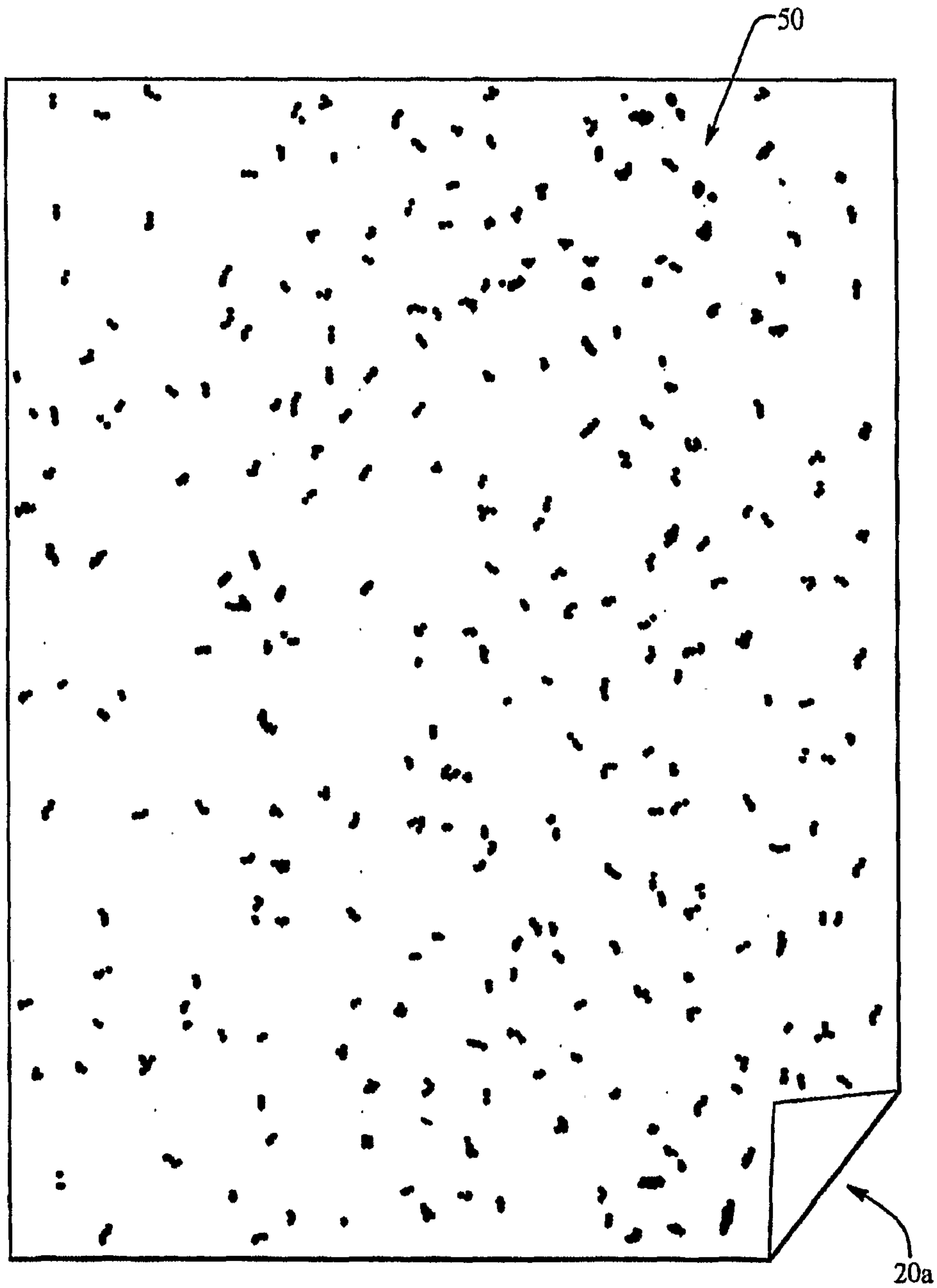
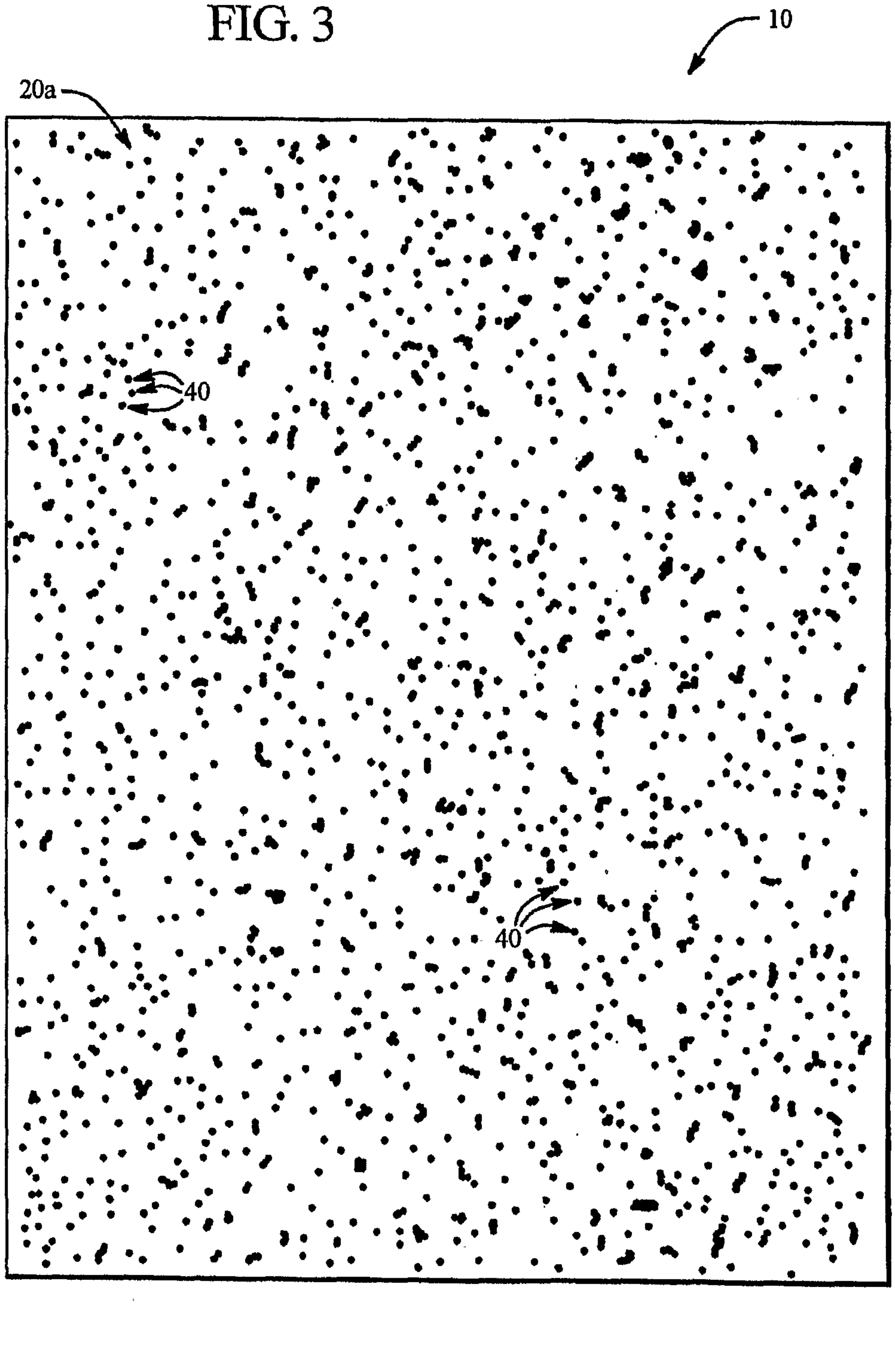


FIG. 3

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