APPLICATION FOR A PATENT

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hereby apply for the grant of a Patent for an invention entitled (d)

METHOD OF FORMING A COMPOSITE BUILDING
STRUCTURE AND STRUCTURE SO FORMED

which is described in the accompanying (e) complete specification.

(Note: The following paragraph applies only to Convention applications)

This application is a Convention application based on the basic application(s) for a patent or similar protection identified by number, country, and filing date as follows:

(6)

675,365 UNITED STATES OF AMERICA 9th April, 1976

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Dated (g) 8 January 1980

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Patent Application

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hereby apply for the grant of a Patent for an invention entitled

(c) TYPICAL OF FORMING A COMPOSITE BUILDING STRUCTURE AND METHOD TO USE

which is described in the accompanying (e) complete specification.

(Note: The following paragraph applies only to Convention applications)

This application is a Convention application based on the basic application(s) for a patent or similar protection identified by number, country, and filing date as follows:

(f) 575,685 UNITED STATES OF AMERICA 30 April, 1978

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Dated (g) 5th April, 1978

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Method of Forming a Composite Building Structure
and Structure so Formed

Claim 1. A method for producing composite structures comprising: inflating an airform; spraying onto the airform a layer of insulating material having low density, low structural strength and low thermal transmission characteristics; curing the sprayed insulating material; maintaining the inflation of the airform; applying a curable structural material onto the airform-insulating material structure; and supporting the composite airform, insulating material and structural material with air pressure until the structural material cures and serves to support the structure.
METHOD OF FORMING A COMPOSITE BUILDING STRUCTURE AND STRUCTURE SO FORMED

The following statement is a full description of this invention, including the best method of performing it known to applicant(s):
The present invention relates generally to a method for forming composite structures of a pneumatic airform, a low density, low strength, dampening and insulating material, and a structural layer such as a cementitious material, and more particularly to a method for forming economic structures by spraying insulating material onto an inflated airform and maintaining the inflation of the airform to support a further layer of structural material, and such structures.

Despite an attractive simplicity, the use of pneumatic airforms to form sprayed, dense structural materials such as cementitious materials, has proven difficult. Such dense materials tend to distort and vibrate the airform. Particularly when spraying on the interior of the airform, these materials are displaced by such disruptions.

However, the advantages of utilizing a pneumatically inflated form as the initial structure in a sprayed foam polymeric structure has been recognized and is well described in U.S. Letters Patent 3,277,219 issued October 4, 1966 to Lloyd S. Turner.

According to the prior art, a two step process is employed to produce a polymeric form for a more durable material such as concrete. First, a pneumatic airform is inflated. Thereafter, a lightweight material, such as a plastic foam, is sprayed against an inner surface of the inflated airform to build up a self-supporting polymeric foam form which will
provide independent initial support to further layers of such as of reinforced concrete or the like. An air compressor or fan is maintained in operation from the time the pneumatic air-form is initially inflated until the foam spraying operation is completed. Thereafter, since the polymer foam is specifically disclosed as constituting a self-supporting layer of adequate thickness and strength to support itself and subsequent layers of structural material, such as sprayed concrete without the assistance of the original air pressure, the compressor or fan is taught to be no longer needed. After the self-supporting layer of foam is hardened, it is characterized as providing a convenient, relatively inexpensive form for the concrete layer. The reinforced concrete layer is taught as affording the structure primary strength and durability, and it is further taught that it is not necessary to remove the foam layer after the concrete layer has hardened since the foam layer would contribute insulation qualities to the structure.

The Turner method has been found to be quite advantageous for the structures contemplated. However, in large structures, it becomes uneconomical to provide a self-supporting foam layer as the initial support for the layer of cementitious or other structural material. In order to provide a self-supporting foam layer, it is necessary that such layer be uneconomically thick. While the basic concept of Turner
provides an advantageous relationship between the layers for small structures, i.e., three to five inches of foam provides a initial, self-supporting form for the concrete layer. However, when larger structures are involved, the thickness of foam quickly reaches a point of diminishing returns in that additional thickness does not provide meaningful additional insulating qualities. Thus, large structures utilizing a self-supporting foam layer have not been economically feasible. Also, the Turner method is of use essentially only with relatively expensive foamed polymers having adequate strength to form a self-supporting form. Cheaper, non-polymer insulating materials have insufficient strength to become "self-supporting" as defined by Turner.

The present invention provides an improvement over previous methods and structures.

According to the invention, there is provided a method for producing composite structures comprising: inflating an airform; spraying onto the airform a layer of insulating material having low density, low structural strength and low thermal transmission characteristics; curing the sprayed insulating material; maintaining the inflation of the airform; applying a curable structural material onto the airform-insulating material structure; and supporting the composite airform, insulating material and structural material with air pressure until the structural material cures and serves to support the structure.

An advantage of the present invention is the ability to produce a structure having optimum insulating values in conjunction with optimum strength provided by a structural
material.

Another advantage of the present invention is the provision of a structure of composite insulating material such as foamed polymers, and a structural material such as cementitious material which, in a preferred embodiment, protects the structural material from thermal shock due to weather changes or other causes.

Yet another advantage of the present invention is the provision of a new and improved method and structure which, in a preferred embodiment, permits rapid erection in an enclosed environment.

These and other objects and features of the present invention will become apparent from the following description.

In the Drawings:

FIGURE 1 is a simplified sectioned side view of a structure produced in accordance with the instant invention;

FIGURES 2 through 6 are sectional views showing exemplary alternative arrangements of composite materials in the structure of FIGURE 1;

FIGURE 7 is a simplified sectional view illustrating a preferred method of applying insulating material in accordance with the instant invention;

FIGURE 8 is a view similar to FIGURE 7 illustrating a preferred method of applying structural material according to a preferred embodiment of the instant invention; and
FIGURE 9 is a graph under a typical set of parameters illustrating the thickness of polymeric material required to produce a self-supporting foam form layer for varying spans of a typical dome structure.

Turning now to the drawings, wherein like components are designated by like reference numerals throughout the various figures, a composite structure produced in accordance with the present invention, is illustrated in FIGURE 1 and generally designated by reference numeral 10. Structure 10 is comprised of an airform 12, which may, as illustrated, be integral with structure 10, or, optionally, removable from structure 10, insulating layer 14 and structural layer 16.

Airform 12, when removable, is preferably formed of laminate polyethylene film material. Generally, polyethylene film material is sufficiently waxy as to permit the removal of airform 12 from structure 10. However, if other materials are employed, it may be desirable to include a parting agent on the sprayed surfaces to facilitate removal of airform 12.

In the preferred embodiment, however, airform 12 is purposely bonded to insulating layer 14 and forms an integral part of structure 10. In such cases, polyethylene terephthalate textile material, commercially available as Dacron (a Registered Trade Mark) material, is a preferred material. Nylon is less desirable in that it tends to stretch more readily, has less resistance to radiation, particularly ultraviolet wave-lengths and,
being hydroscopic, tends to be susceptible to dimension change when wet. In any event, it is preferred that permanent textile airform material be coated with urethane materials to provide for water and air impermeability.

For a number of reasons, it is preferred that airform 12 and, accordingly, ultimately structure 10, be in the form of a spherical section. Such configurations provide high strength to material ratios, low exterior surface to volume ratios to conserve energy, and are readily produced. However, though for purposes of the disclosure airform 12 will be shown in the spherical section, it is to be understood that airform 12 can in fact be produced in numerous configurations including more conventional rectilinear arrangements. Vertical walls and flat or sloped roofs are well within the capabilities of the system. However, since the system is inherently capable of easily producing esthetically attractive and strength producing compound curves, it is preferred that designs which exploit this inherent advantage of the method be employed.

Layer 14 is primarily a low strength, sprayable insulating layer—preferably a polymeric material having numerous gas voids formed therein. However, other sprayable materials are equally operable and will be readily recognized by one skilled in the art. In addition to providing an insulating function, layer 14, which is configured to the shape of structure 10, concurrently serves other functions.
Insulating layer 14 utilizes sprayable materials which, essentially by definition, have relatively low structural strength, low density and low thermal transmission characteristics. In general, these materials are in the form of two-phase structures in which a solid material incorporates numerous gas voids, preferably closed cell gas voids. Since the insulating materials are lightweight, it is feasible to spray directly onto the tauntly stretched airform 12 without setting up deleterious vibrations tending to shake the material from airform 12. For instance, direct spraying of a dense, structural material such as fluid concrete onto airform 12 often substantially deforms airform 12 upon impact, and thus sets up vibrations causing the concrete to slump and/or fall from airform 12.

In addition to the preferred expanded polymeric material, such as polyurethane foams or urea-formaldehyde foams, other materials may also be employed. For instance, thermoplastic materials in the form of particles or beads—preferably having gas voids therein—may be applied as unmelted particles with tacky surfaces, either as a result of heating or admixture of an adhesive with the particles. Expanded polystyrene particles are typical of such materials. As the particles strike the airform, the tacky surface sticks to the airform the sticking being by cohesion if the particles are heated or by adhesive if an and, of course, to other such particles impacting thereon; adhesive is used. Thus, in addition to the preferred voids within the particles per se, voids are also formed between the particles in that
the particles are adhered at interfaces of relatively small surface area. Simple animal glues or other such adhesives are contemplated.

Yet another useful insulating material is to be found in expanded cellulose or finely chopped, reprocessed, paper which is again admixed with an adhesive material and sprayed onto a supporting surface such as airform 12. The resulting sprayed layer, when the adhesive cures, is not unlike paper mache having low structural strength but excellent insulating qualities. Such paper based insulating material is quite economical and readily available.

Insulating qualities of the various materials may vary somewhat depending upon specific formulation, method of application, degree of expansion, etc., but a typical polymeric foam will, in a six inch layer, have an R42 insulating value and, in a three inch layer, typically have an R21 insulating value. The paper based and thermoplastic materials have roughly similar insulating values. Thus, it can be seen that in most cases, a foam layer beyond three or four inches affords little additional economic insulating values for most conventional needs. Particularly in the case of the paper based materials, a very thick layer would be necessary to provide a self-supporting insulating structure, i.e. one that would support its own weight and a subsequent application of a structural material. While the foamed or expanded polymeric
materials are relatively strong relative to the paper base insulating materials, such materials also tend to be somewhat expensive when utilized as a structural material to produce a self-supporting form, though such materials are very effective and economical as in insulating material when used in optimum amounts.

Summarily, insulating layer 14 in accordance with the instant invention initially provides a dampening layer on airform 12 to permit subsequent application of heavier, structural materials. However, insulating layer 14 does not provide primary structural strength and is not relied upon to support subsequent layers. After structural layer 16 is applied and cured, insulating layer 14 then serves, as discussed below, the function of insulating structure 10 with regard to the internal volume thereof, as well as protecting internal structural layer 16 from thermal shock.

In general, the insulating materials are sprayable and form a cured layer, have a density, in pounds per foot$^3$ (Kg/M$^3$), operably less than 75 (1.00), desirably less than 10 (160) and most preferably less than 5 (80), a thermal conductivity in BTU per hour per foot$^2$ per inch per degree F (calorie per hour per cm$^2$ per cm per degree C) operably less than 1 (1.24), desirably less than .5 (.62), and most preferably less than .25 (.31) and a compressive failure strength in pounds per inch$^2$ (Kg/cm$^2$), usually less than 200 (14), and
most often less than 50 (3.5). Of course the strength of insulating materials are desirably as great as possible, but high strength, sprayable insulating materials are not readily available.

Finally, structural layer 16 is preferably of a cementitious material, i.e. hydraulic cement such as Portland cement, gypsum cement, or gypsum cement, plaster, stucco etc., and preferably of a form which may be sprayed. Useful commercial materials include those under the proprietary processes known as Gunite and Shotcrete. The cementitious materials may be reinforced or unreinforced. In the case of reinforced materials, rebar or mesh material is preferably positioned adjacent insulating layer 14 and the cementitious material then sprayed onto and around the reinforcement. Steel fibers are particularly desirable in that the fibers may be sprayed with the cementitious material.

A particularly synergistic effect is realized in structure 10 illustrated in FIGURE 1, in which insulating layer 14 is disposed towards the exterior of the building relative to structural layer 16 when structural layer 16 is a cementitious material. Cementitious material is an excellent structural component but is subject to hairline cracking and physical degradation when exposed to temperature cycles through the freezing point, and particularly so when in relatively thin layers. On the other hand, insulating layer 14, when of
materials described above, tend to melt or decompose when exposed to elevated temperatures. In the configuration shown in FIGURE 1, an accidental fire within structure 10 would not deleteriously effect insulating layer 14 for a substantial period of time when structural layer 16 is hydraulic cementitious material since the cementitious material is quite inert and resistant to heat. A rather extensive burn time is required before the cementitious material fails and/or transmits sufficient heat to insulating layer 14 to vent insulating layer to the interior of structure 10. On the other hand, insulating layer 14 is quite efficient in protecting the cementitious material of structural layer 16 from temperature cycles due to weather variations. Since the interior of structure 10 tends to be held at a more constant temperature, and since cementitious material as structural layer 16 adds a substantial thermal mass to the interior of structure 10, cementitious material in structural layer 16 is effectively protected from adverse thermal cycles.

In addition to the reinforced and unreinforced preferable cementitious material as structural layer 16, other conventional materials having high strength to weight and volume ratios are also suitable. For instance, glass-reinforced polymers or unreinforced polymers such as epoxies, polyesters, and vinyl compounds are also suitable, though the cost and effectiveness of such structural materials are generally less
than those of the preferred cementitious materials. While it is possible to provide reinforcing in insulating layer 14, it is preferred to limit the use of reinforcing materials, be it micro or macro particles, to structural layer 16. Reinforcing is not only more effective in the stronger materials employed in structural layer 16, but tends to provide thermal paths through insulating layer 14. In any event, the reinforcing materials may be provided in any of the conventional manners. Sprayed chopped glass fibers is preferred with polymeric materials.

Thus the materials suitable for forming structural layer 16 are generally dense, strong, particularly in compression, but usually have fairly high thermal transmission. Cementitious material, and particularly hydraulic cements such as Portland cement, plaster/mortar, etc. are typical of such materials. A sprayable material is preferred, but other means of application such as plastering are operable.

Such structural materials should have a compressive strength in P.S.I. (Kg/cm²) of at least 500 (35), preferably at least 1500 (105) and most preferably at least 5000 (352). To gain strength of such magnitude, structural materials usually have thermal conductivities in BTU per hour per foot² per inch per degree F (calorie per hour per square cm per cm per degree C) of more than 1.5 (1.86), and most often greater than 5 (5.2). Of course such materials
are also very dense, i.e. over 100 pound per foot$^3$ (1600
Kg/M$^3$). Thus it will be recognized by those skilled in the
art that the insulating materials and the structural materials
are distinct and recognizable as such.

Other embodiments of structure 10 are illustrated in
FIGURES 3 through 6. As shown in FIGURE 2, an enlarged cross
section of the arrangement of FIGURE 1 is shown with airform
12 as the exterior surface, an intermediate insulating layer
14, and an interior structural layer 16. The embodiment of
FIGURE 3 is the inverse of FIGURE 2, but has the drawback of
exposing structural layer 16 to thermal variations. However,
in some instances, this approach may be desirable to afford
the exterior of structure 10 a more weather and abrasive
resistant exterior.

In FIGURES 4 and 5, the use of insulating layer 14 exter-
terior of intermediate airform 12 with structural layer 16
interior of airform 12, and, conversely, exterior structural
layer 16 and interior insulating layer 14 sandwiching airform
12 are illustrated. In general, the embodiments of FIGURES
4 and 5 present more difficult construction problems while
affording little functional advantage. However, the versa-
tility of the process is illustrated by these configurations.

Finally, in FIGURE 6, a particularly involved structure
is illustrated. Airform 12 has both interior and exterior
insulating layers 14 sprayed thereon. Finally, two structural
layers 16 are provided on both the interior and exterior insulating layers 14. In general, this embodiment is more complex to produce and there is little advantage to two insulating layers 14 over a single layer of a thickness equal to the cumulative thickness of the two layers. In some instances, however, it may be desirable to have a structural layer 16 on both the interior and exterior of structure 10.

In short, depending upon the environment of structure 10, airform 12, insulating layer or layers 14 and structural layer or layers 16 may be produced in many combinations.

The method of producing structure 10 will be more readily apparent with reference to FIGURES 7 and 8. As shown in FIGURE 7, airform 12 is inflated by means of a compressor 18 communicating by, for instance, hose 20, with a closed volume defined at least in part by airform 12. Thus, airform 12 is inflated to form an initial stable form. While various circumstances may enter into the pressure applied to the interior of airform 12, on the order of 0.144 P.S.I. (1.0 Kg/M²) is generally more than adequate to provide a stable, taut configuration of airform 12. Of course, in the preferred single skin airform 12, a force tending to part airform 12 from the ground or other support upon which it is positioned equal to the projected area of airform 12 times the pressure is produced. However, numerous means are available for securely tying airform 12 to its support.
Such forms and tie means are discussed in part in the afore-
mentioned Turner U.S. Letters Patent 3,277,219. Other forms
of airform 12 avo.d this problem.

After airform 12 is inflated, means are provided to
position an operator adjacent, in the preferred embodiment,
the interior of airform 12. As illustrated, lift 24 con-
trollable by an operator is provided. Of course scaffolding
or other such means could also be used. The components of
the insulating material are conventionally prepared and/or
mixed at source 26, pumped through conduit 27, and sprayed
through nozzle 30 onto airform 12 to form insulating layer
14. When insulating layer 14 is complete, structural layer
16 is then, as shown in FIGURES 8, preferably sprayed onto
insulating layer 14. Insulating layer 14, though not self-
supporting, serves to stabilize and dampen airform 12 to per-
mit spraying or other application of structural layer 16.
As a critical point of the instant invention, contrary to
the prior art, insulating layer 14 is not sufficiently self-
supporting to function as a free-standing form for structural
layer 16, the operation of compressor 18 is maintained even
after the spraying operation of insulating layer 14 is com-
plete. Upon initiation of the spraying of structure layer
16, it may be desirable to increase the air pressure within
structure 10 to a level of about 15 or 16 P.S.I. (75 Kg/M²)
to afford greater rigidity to the non-supporting insulating
layer 14. While greater air pressure may, in some embodiments, tend to increase the forces imposed upon the tie downs of airform 12, the weight of insulating layer 14 and structural layer 16 are counter forces which tend to offset the forces at this interface. Thus, as more material in the form of insulating layer 14 or structural layer 16 is sprayed onto structure 16, greater pressure may be maintained within structure 16.

Though illustrated in FIGURES 7 and 8 as being formed from the interior in the preferred embodiment of the invention, it is also, of course, feasible to spray insulating layer 14 and/or structural layer 16 onto the exterior of airform 12. This latter approach, however, has the disadvantage of complicated lifting means which will cantilever workers over airform 12 and tends to negate the value of airform 12 as an exterior, weather protection for insulating layer 14. On the other hand, it is usually necessary to provide workers with protection against fumes when applying polymeric material within airform 12.

As shown in FIGURE 9, a plot of the critical thickness in inches is shown as the ordinate versus dome span in feet as the abscissa. As labeled, plots are provided for two pound per foot$^3$ and for four pound per foot$^3$ foam insulating material. The conditions illustrated are for a typical 50° dome and assuming that the foam must support eleven pounds of
foam, structural material, etc., per ft. of foam. Thus, for these typical conditions, a given span is considered to be "non-supporting" in the area to the right of the appropriate plot line. Accordingly, it can be readily seen that large spans are either non-supporting or require uneconomical thicknesses of insulating material to provide adequate support for the foam itself and a typical second layer of structural material.

Summarily, the instant invention provides for construction of composite structures which more fully utilize the specific structural characteristics of the materials employed, i.e., low density, low strength insulating material and dense, high strength structural material in the composite structure. For instance, the insulating layer is not employed as a structural form for subsequent layers as has heretofore been the case, but as a lightweight, highly insulating material which is applied only in sufficient thickness to optimize these characteristics. Rather than relying upon the insulating layer to provide for structural strength, a structural material may be applied to the non-supporting insulating layer by maintaining or increasing the pneumatic pressure within the airform. As a result, large span domes utilizing only optimum thicknesses of insulating and structural materials may be economically and easily produced.

Although only several embodiments of the present invention
have been illustrated and described, it is anticipated that various changes and modifications will be apparent to those skilled in the art, and that such changes may be made without departing from the scope of the invention as defined by the following claims.
THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method for producing composite structures comprising: inflating an airform; spraying onto the airform a layer of insulating material having low density, low structural strength and low thermal transmission characteristics; curing the sprayed insulating material; maintaining the inflation of the airform; applying a curable structural material onto the airform-insulating material structure; and supporting the composite airform, insulating material and structural material with air pressure until the structural material cures and serves to support the structure.

2. A method for producing composite structures as set forth in Claim 1 in which the insulating material is applied to the interior of the airform.

3. A method for producing composite structures as set forth in Claim 1 or 2 in which the insulating material is a polymer.

4. A method for producing composite structures as set forth in Claim 3 in which the polymer is foamed.

5. A method for producing composite structures as set forth in any one of Claims 1, 2 and 3 in which the insulating material is formed by propelling particles having tacky surfaces towards the airform and joining the particles at the surface.

6. A method for producing composite structures as set forth in Claim 5 in which the particles are joined by cohesion.

7. A method for producing composite structures as set forth in Claim 5 in which the particles are joined by
adhesion.

8. A method for producing composite structures as set forth in Claim 5 or 7 in which the particles are of cellulosic material in the form of expanded cellulose or finely-chopped paper.

9. A method for producing composite structures as set forth in any one of Claims 1 to 8 in which the insulating material has a thermal conductivity less than 1.24 calories per hour per cm² per cm per degree C and a density less than 1200 kg/M³.

10. A method for producing composite structures as set forth in any one of Claims 1 to 8 in which the insulating material has a thermal conductivity less than 0.62 calories per hour per cm² per cm per degree C and a density less than 160 Kg/M³.

11. A method for producing composite structures as set forth in any one of Claims 1 to 8 in which the insulating material has a thermal conductivity less than 1.24 calories per hour per cm² per cm per degree C and a density less than 80 Kg/M³.

12. A method for producing composite structures as set forth in any one of Claims 1 to 11 in which the structural material is a hydraulic cementitious material.

13. A method for producing composite structures as set forth in any one of Claims 1 to 11 in which the structural material is a glass fibre reinforced polymeric material.

14. A method for producing composite structures as set forth in any one of Claims 1 to 13 in which the structural layer when cured has a compressive strength of
at least 35 Kg per cm$^2$ and a density greater than 1600 Kg/m$^3$.

15. A method for producing composite structures as set forth in any one of Claims 1 to 13 in which the structural layer when cured has a compressive strength of at least 105 Kg per cm$^2$ and a density greater than 1600 Kg/m$^3$.

16. A method for producing composite structures as set forth in any one of Claims 1 to 15 in which the airform is formed of a polyethylene terephthalate textile material.

17. A method for producing composite structures as set forth in any one of Claims 1 to 16 in which the airform is inflated by securing the airform to a supporting surface and producing a pneumatic pressure within the volume defined by the airform.

18. A method for producing composite structures as set forth in any one of claims 1 to 17 in which the pneumatic pressure within the airform is increased as the insulating layer and the structural layers are applied to the airform.

19. A method for producing composite structures comprising: securing an airform to a supporting surface; inflating the airform by pumping air within the volume defined by the airform to inflate the airform to a configuration substantially that of the desired structure; spraying onto the interior of the airform an initially fluid foamed polymeric material having low density, low structural strength and low thermal transmission characteristics to form an insulating layer on the interior surface of the airform; curing the insulating layer; forming a second layer of hydraulic cementitious material by spraying fluid cementitious material onto the insulating layer in amounts greater than can be supported by the insulating
layer; and supporting the airform, insulating layer and cementitious material layer by continuously providing a pressure within the airform sufficient to support such layers until the cementitious material cures.

20. A method for producing composite structures substantially as hereinbefore described with particular reference to the accompanying drawings.

21. A composite structure produced according to the method of any one of Claims 1 to 20.

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Fig. 8

Fig. 9