Oct. 8, 1968 J. BJORKSTEN 3,404,748

INSULATION LAMINATE WITH REINFORCING FIBERS AND CORRUGATED LAYER

Filed Dec. 6, 1967 5 Sheets-Sheet 1

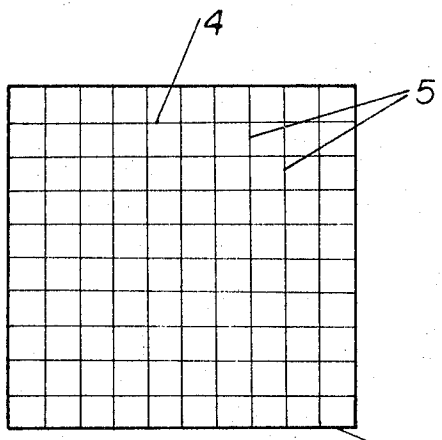


FIG. 1

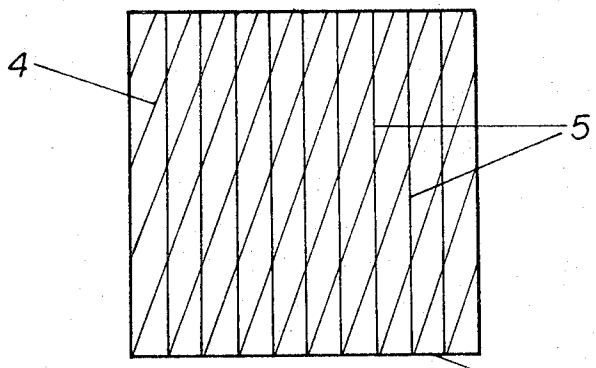


FIG. 2

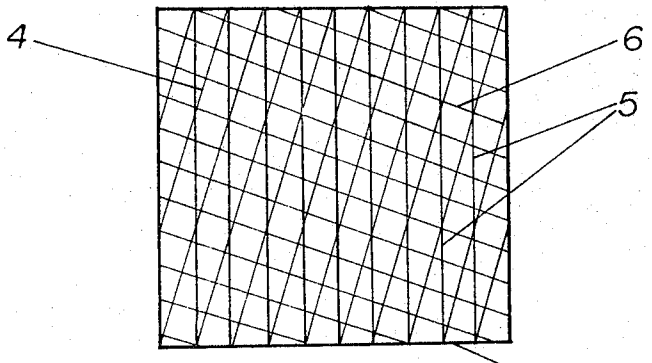


FIG. 3

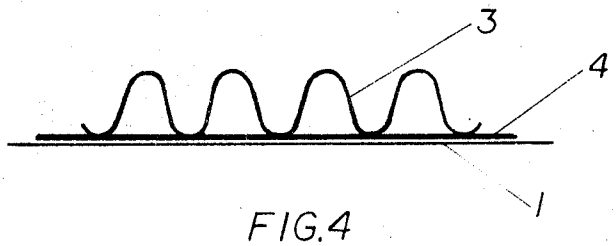


FIG.4

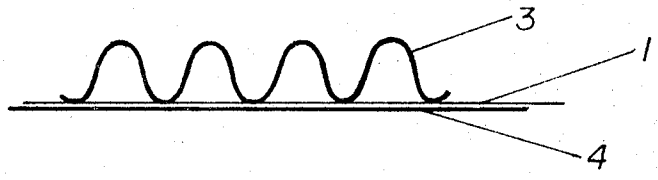


FIG.5

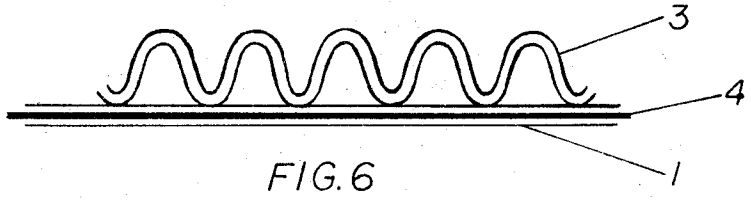


FIG.6

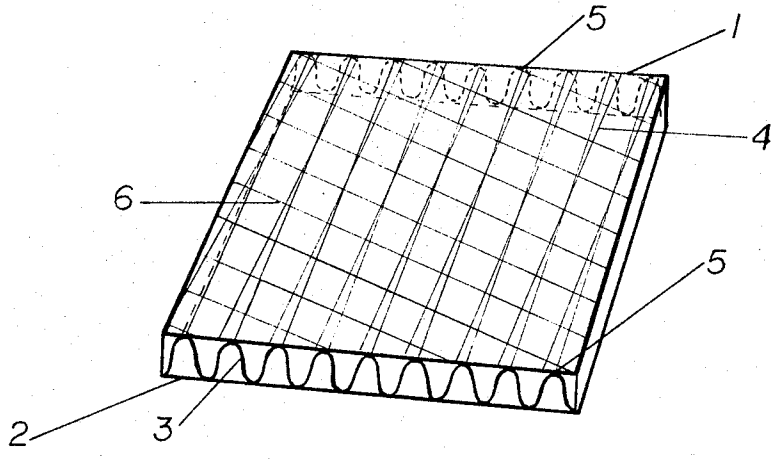


FIG.7

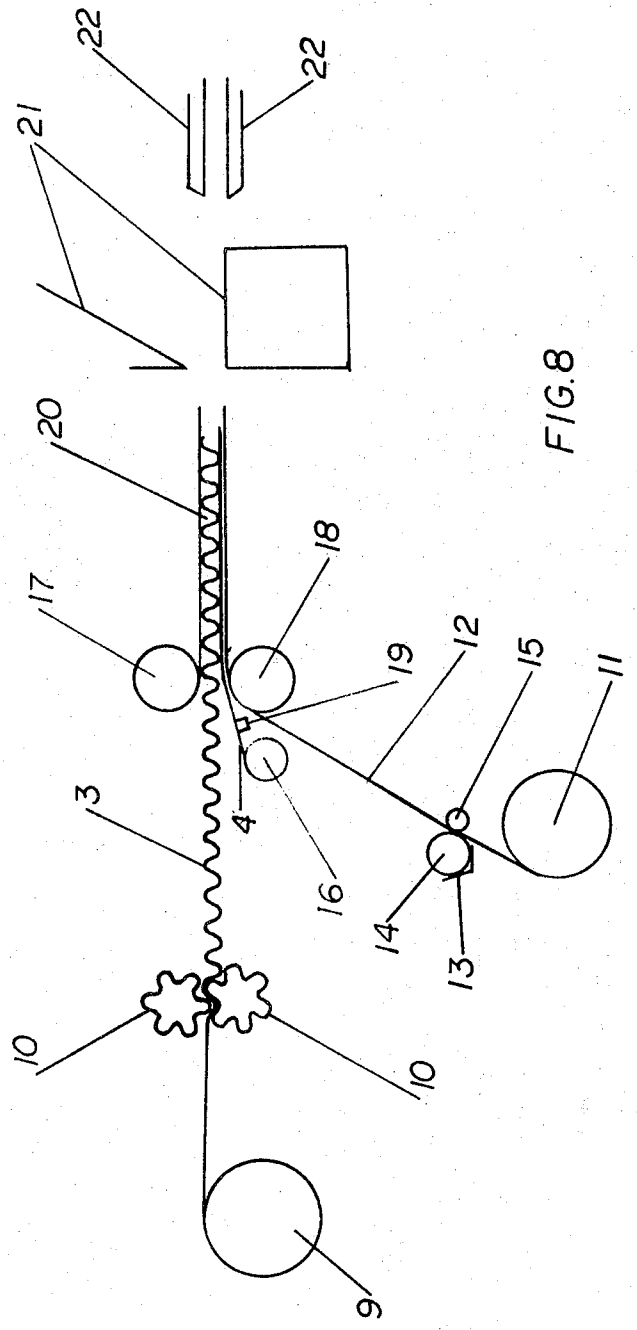


FIG.8

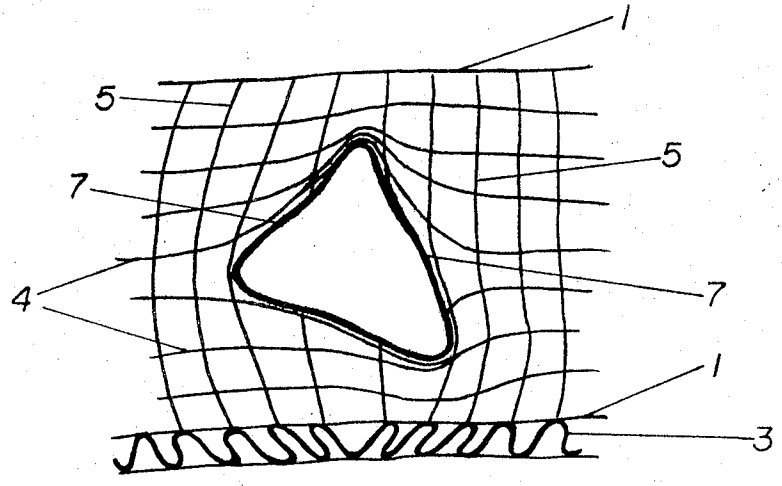


FIG. 9

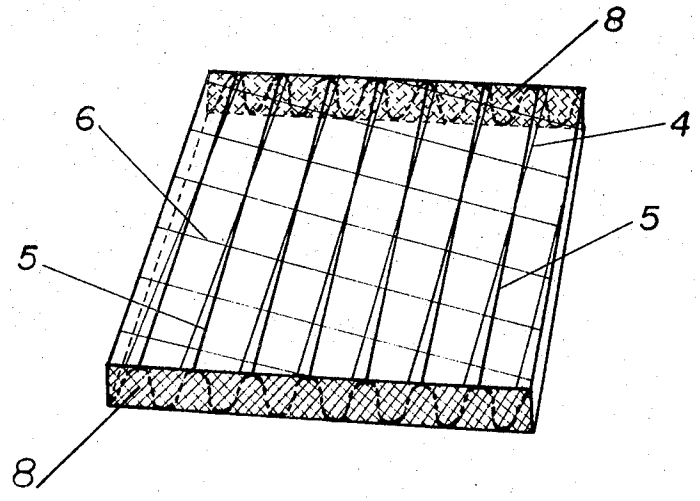


FIG. 10

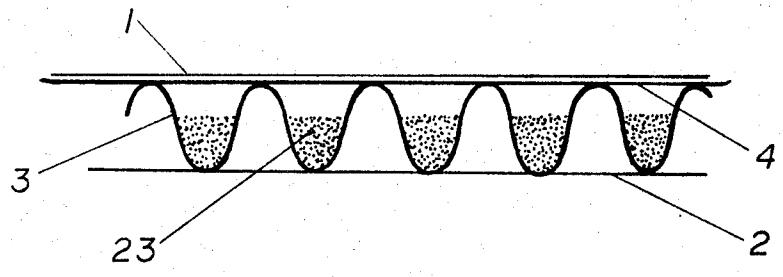


FIG. 11

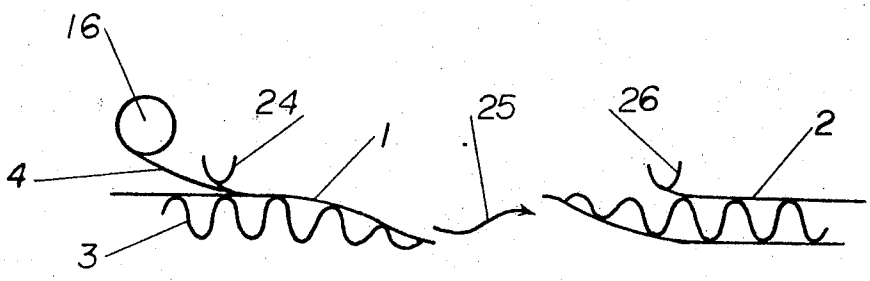


FIG. 12

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3,404,748

INSULATION LAMINATE WITH REINFORCING FIBERS AND CORRUGATED LAYER

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Continuation-in-part of abandoned application Ser. No. 426,560, Jan. 19, 1965. This application Dec. 6, 1967, Ser. No. 688,389

11 Claims. (Cl. 181—33)

ABSTRACT OF THE DISCLOSURE

No existing film composite is at the same time strong enough and light enough to make possible its use in air supported buildings having unsupported spans 20 to 100 ft. wide, and to have attractive insulating qualities at the same time. This invention contemplates such a material, in which a light, foldable, plastic film or film aggregate is reinforced by fibers in one direction, and by corrugations in another direction.

It has been found that corrugations, in which stress can cause limited motion of the "flutes"; and also the larger cross section of plastic, in sections perpendicular to the flutes, result in increased tensile strength in the direction of the flutes and increased tear strength in directions having angles of 10° or more with the direction of the flutes. Corrugations are thus utilized in foldable composites as elements contributing decisively to tear strength while enhancing thermal and acoustical insulation.

This is a continuation-in-part of my patent application Ser. No. 426,560, filed Jan. 19, 1965, now abandoned, for Flexible Film Composites.

The present invention relates to flexible and foldable film components which have sufficient strength to permit their use in air supported buildings, in igloo type air supported semiballoon type dome constructions, and in sparsely supported roof structures, and which at the same time have insulating properties adequate for economical winter use in artificially heated structures.

Heretofore no material has been available which as a single, low cost material has permitted such use. Reinforced plastic films, such as those based on slidable fibers a disclosed in the patent to R. P. Lappala, U.S. Patent 2,851,389, have sufficient strength and lightness, but they lack insulating properties.

An object of this invention is a low cost, plastic film material which combines strength, lightness and foldability sufficient to permit use in air supported buildings, with good thermal insulating properties.

Another object is such a film composite, which also has acoustical insulating properties.

Another object is a film composite which has reinforcing fibers in the longitudinal direction only, yet has in all directions adequate tensile and tear properties for the uses indicated.

Another object is a composite in which corrugation flutes perform mechanical functions heretofore only attained by the use of reinforcing fibers, cords, wires, strips, or the like.

Further objects will become apparent as the following detailed description proceeds.

In accordance with my invention, I corrugate a sheet of plastic which has enough stiffness so that the corrugations will not collapse but essentially maintain their shapes and/or functions, yet remains flexible and foldable in the direction perpendicular to the corrugations; I laminate to this sheet at least one other flexible foldable sheet to close the corrugations, preferably incorporate in the resultant

laminate between these two sheets at least one layer of reinforcing fibers so that these form at least a 10° angle, and preferably a 70 to 110° angle with the direction of the corrugations.

Surprisingly, I have found that the corrugations impart strength to the laminate, which can be comparable to that imparted by reinforcing fibers and which permits the use of the resultant product over large spans, where foldability is required, while at the same time providing a thermal insulation never before attained in products of like lightness, strength, and foldability.

While I am not committing myself to any theory, it is my belief that the reason for this mechanical effect of the corrugations, not heretofore utilized in composite design, is that under stress the corrugations bend together sufficiently to coact much in the same manner as slidable fibers can slide together and form a bunch which renders further propagation of an incipient tear virtually impossible. In addition, the larger amount of material contained in the cross section of a corrugation as compared to a cross section of flat film of similar thickness, will contribute to enhanced tensile strength in the lateral direction. Referring to the drawings, FIGS. 1 through 3 are top views, FIGS. 4, 5, 6 and 11 longitudinal sectional views, FIGS. 7, 9 and 10 perspective views, FIGS. 8 and 12 longitudinal diagrammatic views.

In FIG. 1, the simplest case of the invention is shown: a square pattern, in which the reinforcing fibers **4** are perpendicular to the ridges **5** of the corrugations or flutes. In FIG. 2, the angle between these is about 10°, in FIG. 3 two layers of reinforcing fibers **4** and **6** are used, forming angles of about 10 and about 100° with the corrugations. In the side views, FIG. 4 corresponds to FIG. 1, the reinforcing fibers **4** being placed between films **1** and **3**; in the embodiment shown in FIG. 5 the fibers **4** are adhered to the outside of film **1**, and in FIG. 6 film **1** is soft and formable, and fibers **4** are placed in the middle of the film **1**. In this case, film **1** is highly plasticized or made of a soft polymer, so that the resistance to lateral movement within the film is less than the breaking strength of the fibers, thus permitting the fibers to move within or with the film to bunch up and resist tear together. **3** designates the corrugated sheet.

These embodiments can be made in many ways: by hand layup, or by machines of various types. For example, the fibers may be introduced into the bite between rollers in a laminating machine, or onto the film prior to coating or extrusion of a second film on top of it, or they may be supplied as preformed scrim, so long as the fibers remain slidable in the sense that they can move into bundles when exposed to stresses, and thus coact to resist tears, as shown in FIG. 9, where **7** is the tear and fibers **4** and corrugations **5** coact to limit the damage.

FIG. 7 shows in perspective view a laminate in which the corrugated sheet **3** is sandwiched between two flat sheets **1** and **2**. **5** is the ridge of the corrugations as these touch sheet **1** and **4**, the reinforcing fibers.

FIG. 10 is a perspective view of the embodiment shown in FIGS. 1 and 4, and in which the flutes have been closed at their ends **8** to provide enclosed air spaces in the flutes.

FIG. 8 illustrates a way to produce these embodiments in continuous operation:

Roll **9**, comprises a supply of 3 mil calendered substantially nonplasticized polyvinyl chloride film which is being fed between heated corrugating rollers **10** so as to produce the corrugated sheet **3**. The temperature control is precisely maintained, for example, by electrical or other thermostatic means (not shown). The temperature and rotational speed of rollers **10** are adjusted so as to achieve permanent corrugation but not destruction of said film. Simultaneously a film **12** which may be similar

to the film on roll **9** or may be more highly plasticized or of different gauge as may be desired is supplied from roll **11**. Film **12** is coated with an adhesive by suitable means which may, for example, be a sprayer, an extruder, a doctor knife, but in this drawing is represented as an adhesive supply **13**, a transfer roller **14** and a pressure roller **15**. The adhesive may be a hot melt, or pressure sensitive; if it is a solvent adhesive drying means for solvent removal should be inserted—they are not shown in this drawing. I may also apply adhesive to the corrugated film by similar means, instead of or in addition to the application shown; these additional adhesive applicators are omitted because of clarity, and because they are optional.

The corrugated film **3** and the flat film **12**, at least one of which now carries an adhesive, are brought together between rollers **17** and **18**, so as to cause them to adhere to each other, forming a laminate. Concurrently, longitudinal fibers **4** are fed into the bite between rollers **17** and **18** from warp beam **16**, optionally thru an angle adjusting device **19** employed only when angles other than 90° with the direction of the corrugations is desired. The finished laminate **20** may be taken up on a storage roll (not shown) or may be immediately sheeted on a cut off device **21**, and the edges may be closed to enclose the air in the flutes by means of a suitable means such as a heat sealer **22**.

While a specific arrangement has been shown in this case, it is not my intention to limit the application of the invention to this particular system as the skilled engineer will recognize many ways in which the same effects can be attained. The particular rollers, corrugating wheels, guides, etc., should therefore be viewed as means which will include the equivalent mechanical means for performing similar functions.

FIG. 11 shows a cross section of a laminate in which the flutes **3** contain from about 1/10 to about 3/4 of their volume of a movable granular material **23**, to improve the acoustical properties.

Example I

A 5′ x 25′ cover was made in which the outer skins consisted of 1½ mil soft polyvinyl chloride plasticized with any of the non-migrating plastics and the corrugated core was of non-plasticized "rigid" 3 mil calendered polyvinyl chloride; the length of the corrugations was ⅜″, and the distance between the walls of the corrugations was ¼″. The material was heat-sealed along the edges with a half-inch heat seal obtained by pressing together between jaws heated to the sealing temperature of the vinyl sheet, the reinforcement being 400-denier polyethylene glycol terephthalate fibers spaced ½″ apart diagonally crossing each other in 45° angle against the sides of the longitudinal direction of the article, all parallel fibers being in the same plane, without interweaving in the structure.

Example II

A continuous piece of insulation was made of theoretically unlimited length, 58″ wide. It comprised substantially unplasticized polyvinyl chloride sheets of four-mil thickness, of which two were straight, constituting the outer skins and the third was corrugated with ½″ corrugation depth, ¼″ corrugation distance. Outer skins of five-mil rigid polyvinyl chloride were bonded thereto with an adhesive, this adhesive being a 50% solution of low molecule polyvinyl chloride in methylethyl ketone, this polyvinyl chloride having a softening point 30° F. below the softening point of the corrugated material, and consequently being softer than these and permitting less slippage. The assembly was reinforced by a grid of 300-denier polypropylene fibers placed diagonally, ½″ apart, set in the adhesive adjacent both of the skins. All outer edges were bonded by means of the adhesive above mentioned, under pressure, so as to form an enclosed article suitable for thermal insulation. The edges were sealed by induction heating of aluminum flake pigment dispersed in said films.

Instead of the polyvinyl chloride or polyvinylidene chloride films mentioned above, I may employ other non-flammable films such as non-flammable polyester films, for example, based on halogenated polyols or on hexachloroendomethylene tetrahydrophthalic anhydride, on polychlorofluoroethylenes, and the like. Edge sealing may be done by any form of suitable sealing or welding of the plastics including adhesive sealing and sealing by means of application of a moderate amount of a volatile solvent for the said plastics, so as to cause a solvent welding of the edges. As the reinforcing fibers I may use any synthetic polymer filament of high strength properties such as polypropylene fiber, polyethylene fibers, nylon, polyethylene glycol terephthalate, and the like.

Example III

A four-mil sheet of calendered substantially non plasticized or "rigid" polyvinyl chloride film was passed between heated corrugating rollers (not shown) so as to make this film corrugated, the corrugations being ½″ long and ¼″ wide and ¼″ apart from each other. This corrugated film **3** (FIG. 12) was passed under an extruder head **24** which continuously extruded a softer plasticized or lower molecular plastic film so that this was stretched by the rapidly moving corrugated film, thus forming outer skin **1**. The film could be subsequently twisted 180° by longitudinal guides indicated at **25** and passed under an additional extruder head **26** to lay down a film to form a similar skin **2** of polyvinyl chloride on the other side of the corrugation. In this process, fibers of polypropylene **4** were fed in from roller **16** onto the corrugation between extruded film and the corrugation so as to obtain longitudinal reinforcing fibers. The corrugations themselves act as adequate transversal reinforcements. The softer film may also be a polyvinyl chloride compound or a polyene, acrylate, copolymer, etc. In this application it takes the place of adhesive permitting the sliding action of the fibers in case of stress. The reinforcing fibers were spaced 1/10″ from each other.

The resultant composite has thus very high strength both longitudinally and transversely and, on sealing of the sides, provides effectively sealed air and correspondent floating and insulating properties.

When a "seal" is referred to in this application, I mean therewith the result of any process for joining the sheet materials in which these are joined to the point of being firmly adherent or for closing the flutes laterally, to prevent air circulation. This includes the various adhesive processes, such as plastic or glue or inorganic cement, welding or fusion, and also the solvent welding processes in which the materials are softened or partly dissolved by the addition of a solvent which then, upon evaporation, leaves a firm seal.

The adhesive used in this invention is suitably a rubber elastomer adhesive, such as a solution of butyl rubber or of an acrylate or acrylonitrile rubber or of ethylene propylene elastomer such as "Enjay 400," in a hydrocarbon solvent such as hexanes, heptanes, benzene, tetrahydrofurane, and the like, or mixtures thereof. To increase tack, I may add to the rubber a minor percentage of polyisobutylene, rosin, or cumarone-indene resins, or the like. I may also use tacky polyether compounds, acrylate or methacrylate compounds, tacky chlorinated aromatics known as "Aroclors" made by the Monsanto Co., or any of the numerous tacky compounds used in adhesives, and I prefer to adjust the strength so that the peel strength is between 1 and 20 and preferably between 5 and 10 pounds on peel in a 1 inch strip, pulling at 3 inches a minute, though a range of from 1 pound up to 25 pounds pull may be useful under some circumstances. The adhesive should be permanently tacky, whereby it is understood that it should continue to hold the fibers with approximately the

same degree of tenacity even over storage times extending over years. It is not meant that it must necessarily be tacky to the touch, as the human touch is not sensitive to the degrees of tack used under some of the conditions where this product is intended to be used. The adhesive applicator may be, for example, an engraved or a line-scored metal roller, or it may be a felt wick, or it may be a roller partly dipped into the adhesive, with adhesive being supplied under gravity or artifical pressure or a spray device. In fact, the technique by which the adhesive is applied is not material to the invention, nor the particular way in which the corrugations are formed.

It is also possible to apply the adhesive continuously to the flat film which is being attached and laminated to the corrugated film. In this case, it is possible but no longer necessary to apply adhesive also to the corrugations. However, applying the adhesive to the tops of the corrugations is a more economical procedure, inasmuch as applying it to the film will cause a waste of the adhesive in those areas where the upper film would not contact the lower film because of said corrugations.

When the peel strength of the adhesive is within the limits above stated, it will be found that the product will be extremely resistant to tear. When a tear is started, in any transversal direction for example by cutting into an edge of the article and trying to pull it apart at the rip, the fibers will slide sideways and bunch to form a rope along the edge of the rip. The rope thus formed will impose extreme resistance to any further tearing. If a tear is started in the longitudinal direction, the multiple corrugations will have the effect of absorbing tearing stresses so that in this direction, likewise, a high degree of resistance will be encountered, as shown in FIG. 9.

By utilizing this corrugation technique which does not require complex winding equipment but can be operated at high speed, it is possible to produce the articles of this invention at speeds in excess of 1000 feet per minute. Particularly at high speeds I prefer to apply artificial heat such as electrical heat or circulating heated oil to the corrugating roller **10** and/or to preheat the film in a hot air oven, or by infrared radiation or otherwise, so as to facilitate the formation of corrugation at high speeds.

Of course it is possible to utilize the corrugations for auxiliary effects such as treatment with reflecting media, lamination with reflecting media such as aluminum or metallized fabrics or foils, superimposition of foams or introduction of foaming substances or filling substances into the corrugation, similar use of acoustical material and the like.

While particular reference has been made to plastic films, since these have generally proven most satisfactory for the composites here in view, it is entirely possible to use one sheet of a flexible metal, such as aluminum film or a film of steel, preferably stainless, or the extremely thin adherent metal film accomplished by vapor deposition onto one of the plastic films used. This is useful for equalizing heat distribution, thus preventing hot spots in processing, by accomplishing shielding, and to achieve electrical and thermal conductivity, and freedom from static electricity. Thermal reflectance may also be desirable when these materials are to be used as protection against flash heat, or for insulation where the temperature gradients are sharp.

While reference has been made to specific embodiments of the invention by way of illustration, it is understood that the invention particularly contemplates composites in which a part of the tear strength is supplied by the mobility under stress of the flutes of the corrugation as well as the larger amount of plastic present in the corrugations as compared with flat sheet of the same thickness spanning the same width. This heretofore unsuspected structural potentiality of the corrugations when used in accordance with this invention, makes it possible to achieve the multiaxial reinforcement effect needed, for example, for air pressure supported structures, by means of monodirectional fiber reinforcement. This greatly simplifies production and reduces cost.

Additional fibers in other directions may be used if desired, but are not necessary for the function of the invention when the mechanical reinforcing potentialities of the corrugations are properly utilized.

The resultant product is foldable, it can be rolled up in rolls in the direction perpendicular to the corrugations, and it has thermally insulating properties commensurate with the amount of air entrapped in and between the flutes of the corrugations and abutting films. Noise absorbency may be enhanced by filling the corrugations with movable granular material in whole or in part, for example to the extent of about $\frac{1}{10}$ to $\frac{3}{4}$ of the volume of said flutes. Such added material can also be used to further enhance thermal insulation.

The ends of the flutes may be closed, for example, by heat sealing, or by adhesive sealing, or filling with putty, or with plugs or in any other manner.

The reinforcing fibers are preferably oriented plastic fibers, threads, strips, cords or monofilaments and I understand the term "fiber" to embrace any flexible, high strength highly elongated reinforcing members of any flexible, foldable material. I include among the usable material also metal fibers and glass fibers although glass and other ceramic fibers are generally not preferred because of their tendency to interfibral abrasion on flexing.

Of the usable plastic materials, both for film and fibers, I prefer those which are non-combustible, such as polyvinyl chloride, preferably 1–10 mil calendered non-plasticized film; polyfluoroethylenes, polyvinylidene halides, and the like. For non-construction uses I may also use combustible plastics, such as polyene plastics e.g., polyethylene, polypropylenes, copolymers and terpolymers of these, polyether and polyester fibers, and the like. The requirement for non-combustibility applies principally to the films—for fibers it is much less stringent because of the lesser mass of the latter in the composite.

Having thus disclosed my invention, I claim:

1. As a new article of manufacture, a foldable thermally insulating composite film comprising a corrugated film sufficiently stiff to maintain its shape when formed into corrugated flutes; at least one substantially flat film bonded thereto, and parallel fibers, spaced at least $\frac{1}{10}$" apart from each other, the fibers being slidable relative to any tear so as to bunch under stress to form substantially non-tearable bundles limiting the propagation of any tear formed, said reinforced fibers forming an angle of at least 10° with the direction of the flutes of the said corrugation.

2. As claim **1**, the said fibers forming an angle of between 70° and 110° with the said flutes.

3. As claim **1**, the said angle being 90°.

4. As claim **1**, the said fibers being disposed between the said two films.

5. As claim **1**, the said flutes being closed at their ends.

6. As claim **1**, the said flutes containing at least $\frac{1}{10}$ of their volume of a movable granular material.

7. As claim **1**, the said films being of a non-combustible plastic.

7. As claim **1**, the said films being of a non-combustible plastic.

8. As claim **1**, the said corrugated film being of substantially unplasticized polyvinyl chloride.

9. As claim **1**, at least one of the said films being of polypropylene.

10. As claim **1**, the said fibers being contained within the flat film and having a tensile strength exceeding the tear strength of the said film, so as to permit a bunching of said fibers in response to stress.

11. As claim **1**, the said fibers being bonded to the surface of at least one of the said films with a bond weaker than the tensile strength of said fibers, so as to permit a bunching of said fibers in response to stress.

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