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(54) **FIBER REINFORCED COMPOSITE SHEATHING FOR STORM PROTECTION**

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(57) **ABSTRACT**

A composite suitable as an integral portion of a building affording protection from wind blown debris such as from a tornado comprises a first layer of fabric of high strength fibers bonded with a resin and a second layer of a structural sheathing material such as plywood.

FIBER REINFORCED COMPOSITE SHEATHING FOR STORM PROTECTION

TECHNICAL FIELD

[0001] The invention relates to the use of a high strength laminated composite sheathing for the reinforcement of walls and doors to resist penetration by wind-borne debris such as that generated by severe storm events, particularly tornadoes.

BACKGROUND OF THE INVENTION

[0002] Storm shelters and cellars are necessary to provide a safe haven for protection against severe storm events in regions prone to tornado or hurricane activity. These shelters have been typically constructed of poured concrete, steel reinforced masonry, or heavy weight sheet metal. Details of adequate designs for storm shelters and cellars are detailed in publications from the Federal Emergency Management Agency (FEMA) such as Taking Shelter from the Storm—Publication 320 and Design and Construction Guidance for Community Shelters—Publication 361. The current designs rely on the use of common heavyweight construction materials such as concrete and steel to provide the resistance to wind-borne debris generated in the storm event.

[0003] The current designs are not easily incorporated into current building practices, and result in significant weight increases in the wall structure. The wood framing approaches described in FEMA Publication 320 require the in-filling of the wall section with solid masonry or continuous sheathing with 14 gauge steel plate. Doors for these shelters required the reinforcement with a minimum 14 gauge sheet metal to provide the needed penetration resistance. These approaches are cumbersome, difficult to install and difficult to field work to size. In regards to doors, the current solutions result in heavyweight doors that introduce safety issues and poor aesthetics.

[0004] A report dated May 31, 2000 by Clemson University submitted to the Federal Emergency Management Agency entitled "Enhanced Protection for Severe Wind Storms" describes several additional approaches for the reinforcement of shelter walls against wind-borne debris. Concepts included 4 walls (numbers **9**, **10**, **11** & **17**) that made use of Kevlar® cloth. FIG. 12 on page 36 shows that these flexible cloth concepts provided no more than 44% of the impact resistance required to meet the "National Performance Criteria for Tornado Shelters". No concept proposed in this study provided more than 60% of the requirements.

[0005] A substantial need exists for a method to reinforce walls and doors with a lightweight field workable sheathing to provide the penetrative resistance needed for protection from wind-borne debris such as that generated in tornadoes and hurricanes. However wind speeds generated by tornadoes can exceed 200 miles per hour which is greatly in excess of wind speeds generated by hurricanes. Therefore a particular need exists for the lightweight field workable sheathing to withstand wind-borne debris generated by the higher tornado wind speeds.

SUMMARY OF THE INVENTION

[0006] The present invention is directed to:

[0007] a composite comprising:

[0008] (a) a first layer of a fabric containing high strength fibers bonded with a resin wherein the first layer will deflect in a range from 5.0 to 17.5 centimeters employing a 33 kilogram (15 pound) projectile at a speed of 161 kilometers (100 miles) per hour in accordance with ASTM test procedure E1886-97 mounted on one layer of % inch ply wood with #10d nails on a frame in accordance with FEMA Publication 320, Revision 1 specific to Drawings AG-5 and 14, and

[0009] (b) a second layer of structural sheathing.

[0010] The material is particularly adapted for construction of storm shelters and residences located in areas of the world which are subjected to wind-blown debris not only by hurricanes but also from the substantially higher wind speeds of tornadoes.

DETAILED DESCRIPTION OF THE INVENTION

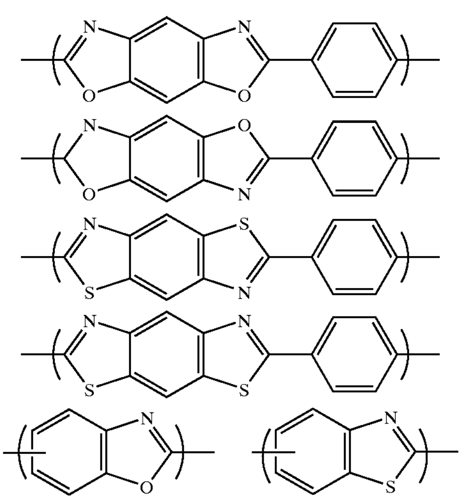
[0011] In formation of a material of construction for protection against wind-blown debris such as generated by tornadoes with wind speeds in excess of 200 miles per hour a necessary starting material is a fabric containing high strength fiber. The fabric may be a woven or non-woven although a woven fabric is preferred. High strength fibers are well known and as employed herein means fibers having a tenacity of at least 10 grams per dtex and a tensile modulus of at least 150 grams per dtex. Yarns can be made from fibers such as aramids, polyolefins, polybenzoxazole, polybenzothiazole, glass and the like, and may be made from mixtures of such yarns.

[0012] The fabric may include up to 100 percent aramid fiber. By "aramid" is meant a polyamide wherein at least 85% of the amide (—CO—NH—) linkages are attached directly to two aromatic rings. Examples of aramid fibers are described in Man-Made Fibers—Science and Technology$_1$ Volume 2, Section titled Fiber-Forming Aromatic Polyamides, page 297, W. Black et al., Interscience Publishers, 1968. Aramid fibers are, also, disclosed in U.S. Pat. Nos. 4,172,938; 3,869,429; 3,819,587; 3,673,143; 3,354,127; and 3,094,511.

[0013] Para-aramids are common polymers in aramid yarn and poly(p-phenylene terephthalamide) (PPD-T) is a common para-aramid. By PPD-T is meant the homopolymer resulting from mole-for-mole polymerization of p-phenylene diamine and terephthaloyl chloride and, also, copolymers resulting from incorporation of small amounts of other diamines with the p-phenylene diamine and of small amounts of other diacid chlorides with the terephthaloyl chloride. As a general rule, other diamines and other diacid chlorides can be used in amounts up to as much as about 10 mole percent of the p-phenylene diamine or the terephthaloyl chloride, or perhaps slightly higher, provided only that the other diamines and diacid chlorides have no reactive groups which interfere with the polymerization reaction. PPD-T, also, means copolymers resulting from incorporation of other aromatic diamines and other aromatic diacid chlorides such as, for example, 2,6-naphthaloylchloride or chloro- or dichloroterephthaloyl chloride or 3,4 -diaminodiphenylether.

[0014] By "polyolefin" is meant polyethylene or polypropylene. By polyethylene is meant a predominantly linear polyethylene material of preferably more than one million molecular weight that may contain minor amounts of chain branching or co-monomers not exceeding 5 modifying units per 100 main chain carbon atoms, and that may also contain admixed therewith not more than about 50 weight percent of one or more polymeric additives such as alkene-1-polymers, in particular low density polyethylene, propylene, and the like, or low molecular weight additives such as anti-oxidants, lubricants, ultra-violet screening agents, colorants and the like which are commonly incorporated. Such is commonly known as extended chain polyethylene (ECPE). Similarly, polypropylene is a predominantly linear polypropylene material of preferably more than one million molecular weight. High molecular weight linear polyolefin fibers are commercially available.

[0015] Polybenzoxazole and polybenzothiazole are preferably made up of polymers of the following structures:



[0016] While the aromatic group shown joined to the nitrogen atoms may be heterocyclic, they are preferably carbocyclic; and while they may be fused or unfused polycyclic systems, they are preferably single six-membered rings. While the group shown in the main chain of the bis-azoles is the preferred para-phenylene group, that group may be replaced by any divalent organic group which does not interfere with preparation of the polymer, or no group at all. For example, that group may be aliphatic up to twelve carbon atoms, tolylene, biphenylen, bis-phenylene either, and the like.

[0017] A further requirement in the present invention is the use of a resin to bind individual fibers of the high strength fibers in the employed fabric. The resin may be selected from a wide variety of components such as polyethylene, ionomers, polypropylene, nylon, polyester, vinyl ester, epoxy and phenolics and thermoplastic elastomers.

[0018] The resin may be applied to the fabric containing high strength fibers by coating or impregnation, such as under pressure.

[0019] However criticality exists in the present invention in the combination of fabric with high strength fibers/resin combination. It has been discovered that this combination must have the ability to deflect within certain parameters when securely fastened to a support material.

[0020] Accordingly the high strength fabric/resin combination must have an ability for deflection when tested in accordance with National Performance Criteria for Tornado Shelters, First Addition, FEMA, May 28, 1999 using ASTM Test Method E1886-97, entitled "Standard Test Method for Performance of Exterior Window, Certain Walls, Doors and Storm Shutters Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials." Highlights of the test include mounting the test specimen, i.e., in present case the combination of fabric with high strength fibers/resin, impacting the specimen with a 33 kilogram (15 pound) 2×4 missile propelled at a speed of 161 kilometers (100 miles) per hour and observing and measuring the test results. The ASTM test procedure E1886-97 is specific to the various requirements such as the use of 2×4 lumber missile, missile propulsion device, speed measuring system and use of a high speed video or photographic camera. It is understood, herein, that the test procedure for purposes of the present disclosure involves attaching any test specimen, i.e., the high strength fabric I resin combination, with one layer of ¾-inch plywood using #10d common nails spaced per the nailing schedule described in FEMA Publication 320, Revision 1, specific to Drawings AG-5 and 14, to a wall frame built in accordance with same publication, with plywood as outermost layer from said frame. Such wall system is then impacted on the plywood face at the center of one of the two middle bays. The 2×4 lumber missile should be marked with suitable indexing marks to allow the tracking of the depth of penetration of the projectile. The photographic or video camera should be positioned to monitor the depth of penetration of the projectile and such camera should have a minimum frame rate of 1000 frames per second.

[0021] In accordance with the described test procedure,, the combination of the fabric containing high strength fibers bonded with a resin will deflect within a range from 5.0 to 17.5 cm. More preferably the deflection will be in a range from 8.0 to 16.0 cm and most preferably 10.0 to 15.0 cm. The degree of deflection may be determined by its final use in a building structure. Illustratively a maximum stated deflection of the fabric/resin combination may be undesirable in a residence due to the proximity of an occupant adjacent a wall containing the cloth/resin combination. However, a minimum deflection within the above range can require an added thickness of the fabric resulting in a high cost of construction. As employed herein, fabric is inclusive of more than one layer of a cloth. As employed herein deflection means the maximum measured distance of separation of the high strength fabric/resin combination from the structural sheathing. It is understood that the measurement must be undertaken in conjunction with high speed photography. For purposes of illustration for deflection measurement, if during the test procedure with the projectile, there may be some bowing of the structural sheathing. The measurement for deflection is the distance, i.e., the separation, of the high strength fabric/resin combination from the bowed portion of the sheathing. It can be determined from review of the photographic or video record collected during previously described testing, determining the maximum depth of penetration during the event, and subtracting the thickness of the structural sheathing.

[0022] The use of a fabric containing high strength fibers, i.e, Kevlar® aramid in combination with plywood has been previously tested in the Clemson University report referenced in the Background of the Invention. However in accordance with the test procedure of this report, complete penetration of the Kevlar® aramid/plywood took place with a nine pound projectile at a speed of 73 miles per hour.

[0023] In the present invention the combination of the fabric containing the high strength fibers/resin is for employment with a wood based or other structural sheathing material, since an additional purpose of the combination is the structural reinforcement of a wall or door. The term "structural sheathing" is inclusive of any material which provides structural building support. The preferred material is wood, particularly plywood, due to extensive use in the building industry. However other materials are known for structural sheathing serving as building support: a typical example is fiberboard reinforced with cement. The fabric/resin combination is generally flexible and will be employed with the sheathing which for purposes of illustration may be at least 0.65 cm (one quarter inch) and preferably for purposes of support, at least 1.27 cm (one half inch). The type of structural sheathing is not critical to the success of the present invention. The sheathing may be solid such as from hard or soft woods or may be in the form of a composite such as plywood or a non-wood sheathing such as cementous fiberboard. As a practical matter, solely from a question of cost, it is believed that most uses of the present invention will be with plywood since it is a common material used in wall structures. There is no maximum thickness to the structural sheathing which in a building structure will be or face an outer wall with the combination of fabric/resin facing the inner portion of the building, i.e., for example a room where inhabitants are to be protected.

[0024] Therefore in construction of a protective shelter or one or more rooms in a residence it is intended that the structural sheathing face the direction of any wind-borne debris such that the debris strikes the wood with penetration before contact and containment with deflection of the combination of cloth/resin. It is understood that the invention is particularly advantageous since conventional building construction and techniques with structural sheathing may be employed.

[0025] It is noted that use of an aramid fiber/wood combination has been disclosed in German DE 195 12582 as claddings of walls, ceilings and floors in indoor firing ranges. However, the requirements of a firing range with a high speed/low weight projectile are entirely different than the requirements of the present invention with wall deflection and with an ability to stop penetration of wind-borne debris due to wind speed of over 200 miles per hour.

[0026] To further illustrate the present invention, the following examples are provided.

EXAMPLES

Example 1

[0027] A 3-foot wide by 4-foot long fiber reinforced composite sheathing panel was prepared by stacking 3 layers of a 13.5 oz./square yard, plain weave fabric made from aramid fiber, between 2 layers of 0.0045 thick film made from an ionomeric polyethylene resin. The stack of fabric and resin was placed in a heated hydraulic press that had been pre-heated to 300° F. A pressure of 160 psi was applied to the stack of material for 1 hour to melt the outer layers of polymer and infuse it into the layers of fabric that were in between. The press was then cooled below 150° F. and the pressure released.

[0028] The resulting sheathing was nailed to a wooden frame made from 2×4 framing timber as prescribed in FEMA Publication 320. #10 power driven nails were used to fasten the composite sheathing to the wooden frame, with a single layer of ¾" plywood covering the sheathing on the face to be impacted.

[0029] The wall panel was mounted on a rigid test frame with the 3-foot dimension on each side of the wall panel fully supported. The sample was impacted with a 15-lb 2×4 timber projectile traveling at 100 mph, to access ability to meet the "Windborne Missile Impact Resistance on Shelter Wall and Ceiling" provisions of the National Performance Criteria for Tornado Shelters, First Addition, FEMA, May 28, 1999. Cannon set-up and firing was done in accordance with ASTM E1886 -97.

[0030] The wall segment stopped the projectile from passing through it as required by the FEMA provisions, and the projectile was rebounded back. High speed photography taken during the event showed the projectile to penetrate approximately 15.2 cm into the wall cavity before being rebounded back. Deflection of the composite sheathing was calculated to be 13.4 cm. The plywood layer on the outside of the wall showed damage only locally around the point of projectile entry.

Example 2

[0031] A 3-foot wide by 4-foot long fiber reinforced composite sheathing panel was prepared by stacking 7 layers of a 10 oz./square yard, plain weave fabric made from S-2 glass fiber, with 4 layers of 0.0045 thick film made from an ionomeric polyethylene resin. The stack of fabric and resin was placed in a heated hydraulic press that had been pre-heated to 300° F. A pressure of 160 psi was applied to the stack of material for 1 hour to melt the layers of polymer and infuse it into the layers of fabric that were in between. The press was then cooled below 150° F. and the pressure released.

[0032] The resulting sheathing was nailed to a wooden frame made from 2×4 framing timber as prescribed in FEMA Publication 320. #10 power driven nails were used to fasten the composite sheathing to the wooden frame, with a single layer of ¾" plywood covering the sheathing on the face to be impacted.

[0033] The wall panel was mounted on a rigid test frame with the 3-foot dimension on each side of the wall panel fully supported. The sample was impacted with a 15-lb 2×4 timber projectile traveling at 100 mph, to access ability to meet the "Windborne Missile Impact Resistance on Shelter Wall and Ceiling" provisions of the National Performance Criteria for Tornado Shelters, First Addition, FEMA, May 28, 1999. Cannon set-up and firing was done in accordance with ASTM E1886 -97.

[0034] The wall segment stopped the projectile from passing through it as required by the FEMA provisions, and the projectile was rebounded back. High speed photography taken during the event showed the projectile to penetrate approximately 11.4 cm into the wall cavity before being rebounded back. Deflection of the composite sheathing was calculated to be 9.6 cm. The plywood layer on the outside of the wall showed damage only locally around the point of projectile entry.

Example 3

Dry Fabric Control

[0035] A 3-foot wide by 4-foot long dry fabric sheathing material was prepared by sewing 3 layers of a 13.5 oz./square yard, plain weave fabric made from aramid fiber around the edges.

[0036] The resulting fabric pack was nailed to a wooden frame made from 2×4 framing timber as prescribed in FEMA Publication 320. #10 power driven nails were used to fasten the fabric sheathing to the wooden frame, with a single layer of ¾" plywood covering the sheathing on the face to be impacted.

[0037] The wall panel was mounted on a rigid test frame with the 3-foot dimension on each side of the wall panel fully supported. The sample was impacted with a 15-lb 2×4 timber projectile traveling at 100 mph, to access ability to meet the "Windborne Missile Impact Resistance on Shelter Wall and Ceiling" provisions of the National Performance Criteria for Tornado Shelters, First Addition, FEMA, May 28, 1999. Cannon set-up and firing was done in accordance with ASTM E1886 -97.

[0038] The wall segment stopped the projectile from passing through it as required by the FEMA provisions, and the projectile was rebounded back. High speed photography taken during the event showed the projectile to penetrate approximately 17.8 cm into the wall cavity before being rebounded back. Deflection of the fabric sheathing was calculated to be 16 cm, which was 2.6 cm more than that noted in example 1 with the resin present. The plywood layer on the outside of the wall also showed significant cracking beyond the point of impact. There was as well, significant pull-out of the fabric around the fasteners.

Example 4

Control

[0039] A 4-foot wide by 8-foot long fiber reinforced composite sheathing panel was purchased from the Sioux Manufacturing Company that had been produced from 3 layers of 13.5 oz/square yard plain weave aramid fabric coated with phenolic resin and molded as described in the MIL-L-6247A specification for ballistic armor.

[0040] The resulting sheathing was nailed to a wooden frame made from 2×4 framing timber as prescribed in FEMA Publication 320. #10 power driven nails were used to fasten the composite sheathing to the wooden frame, with 2 layers of ¾" plywood covering the sheathing on the face to be impacted.

[0041] The wall panel was mounted on a rigid test frame with the 4-foot dimension the wall panel supported. The sample was impacted with a 15 lb. 2×4 timber projectile traveling at 100 mph, to assess ability to meet the "Windborne Missile Impact Resistance on Shelter Wall and Ceiling" provisions of the National Performance Criteria for Tornado Shelters, First Addition, FEMA, May 28,1999. Cannon set-up and firing was done in accordance with ASTM E1886-97.

[0042] The Wall did not stop projectile from passing through it as required by the FEMA provisions and the 2×4 imbedded itself into the wall.

Example 5

[0043] A 3-foot wide by 4-foot long fiber reinforced composite sheathing panel was prepared by stacking 3 layers of a phenolic prepreg produced from 13.5 oz./square yard, plain weave fabric made from aramid fiber in accordance with Mil Spec MIL-L-62474. The stack of prepreg was placed in a heated hydraulic press that had been pre-heated to 330° F. A pressure of 160 psi was applied (versus 200 psi as required by MIL-L-62474) to the stack of material for 30 minutes to cure the resin. The press was then cooled below 150° F. and the pressure released. The resulting material was more flexible than the commercially acquired laminate pressed in accordance with the Military Specification.

[0044] The resulting sheathing was nailed to a wooden frame made from 2×4 framing timber as prescribed in FEMA Publication 320. #10 power driven nails were used to fasten the composite sheathing to the wooden frame, with a single layer of ¾" plywood covering the sheathing on the face to be impacted.

[0045] The wall panel was mounted on a rigid test frame with the 3-foot dimension on each side of the wall panel fully supported. The sample was impacted with a 15-lb 2×4 timber projectile traveling at 100 mph, to access ability to meet the "Windborne Missile Impact Resistance on Shelter Wall and Ceiling" provisions of the National Performance Criteria for Tornado Shelters, First Addition, FEMA, May 28, 1999. Cannon set-up and firing was done in accordance with ASTM E1886 -97.

[0046] The wall segment stopped the projectile from passing through it as required by the FEMA provisions, and the projectile was rebounded back. High speed photography taken during the event showed the projectile to penetrate approximately 10.2 cm into the wall cavity before being rebounded back. Deflection of the composite sheathing was calculated to be 8.4 cm. The plywood layer on the outside of the wall showed damage only locally around the point of projectile entry.

What is claimed is:

1. A composite comprising:

(a) a first layer of a fabric containing high strength fibers bonded with a resin wherein the first layer will deflect in a range from 5.0 to 17.5 centimeters employing a 33 kilogram (15 pound) projectile at a speed of 161 kilometers (100 miles) per hour in accordance with ASTM test procedure E1886-97 mounted on one layer of ¾ inch plywood with #10d nails on a frame in accordance with FEMA Publication 320, Revision 1 specific to Drawings AG-5 and 14, and

(b) a second layer of structural sheathing.

2. The composite of claim I wherein the deflection is in a range from 8.0 to 16.0 centimeters.

3. The composite of claim 1 wherein the high strength fibers are selected from the group consisting of aramid fibers, glass fibers, polyethylene fibers, polyvinyl alcohol fibers, polyarylate fibers, polybenzazole fibers, or carbon fibers.

4. The composite of claim 1 wherein the high strength fibers comprise an aramid.

5. The composite of claim 1 wherein the high strength fibers are glass.

6. The composite of claim 1 wherein the second layer is at a thickness of at least 0.65 centimeters (one quarter inch).

7. The composite of claim I wherein the second layer comprises plywood.

8. A building structure having an integral portion of the structure comprising a composite comprising:

(a) a first layer of a fabric containing high strength fibers bonded with a resin wherein the first layer will deflect in a range from 5.0 to 17.5 centimeters employing a 33 kilogram (15 pound) projectile at a speed of 100 kilometers (100 miles) per hour in accordance with test procedure E1886-97 mounted on one layer of % inch plywood with #10d nails on a frame in accordance with FEMA Publication 320, Revision 1 specific to Drawings AG-5 and 14, and

(b) a second layer of a structural sheathing.

wherein the first layer faces an interior portion of the structure and the second layer faces or comprises an outer layer of the structure.

9. The building structure of claim 8 wherein the integral portion comprises a wall.

10. The building structure of claim 8 wherein the integral portion comprises a ceiling.

11. The building structure of claim 8 comprising the second layer of structural sheathing at a thickness of at least 0.65 centimeters (one quarter inch).

12. The building structure of claim 8 wherein the deflection is in a range from 8.0 to 16.0 centimeters.

13. The building structure of claim 8 wherein the high strength fibers are selected from the group consisting of aramid fibers, glass fibers, polyethylene fibers, polyvinyl alcohol fibers, polyarylate fibers, polybenzazole fibers, or carbon fibers.

14. The building structure of claim 8 wherein the high strength fibers comprise an aramid.

15. The building structure of claim 8 wherein the high strength fibers are glass.

16. The building structure of claim 8 wherein the second layer is at a thickness of at least 1.27 centimeters (one half inch).

17. The building structure of claim 8 wherein the second layer comprises plywood.

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