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(54) **METHODS OF RANDOMLY DISPERSING CHOPPED CARBON FIBER AND CONSOLIDATING THE MATERIALS TOGETHER TO MAKE A FIBER REINFORCEMENT MAT**

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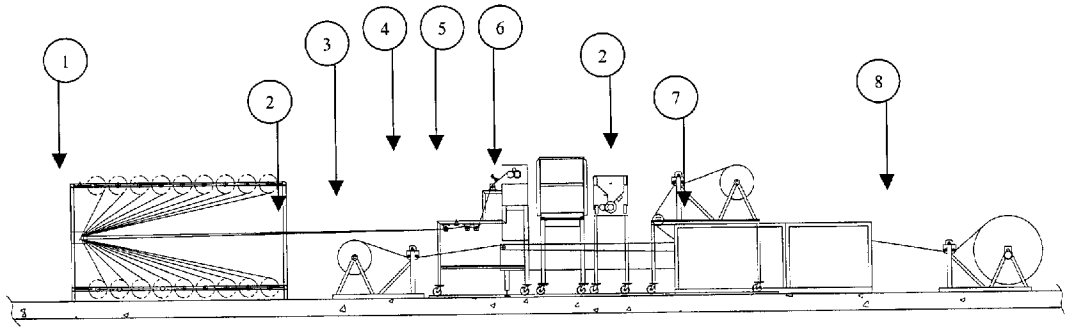
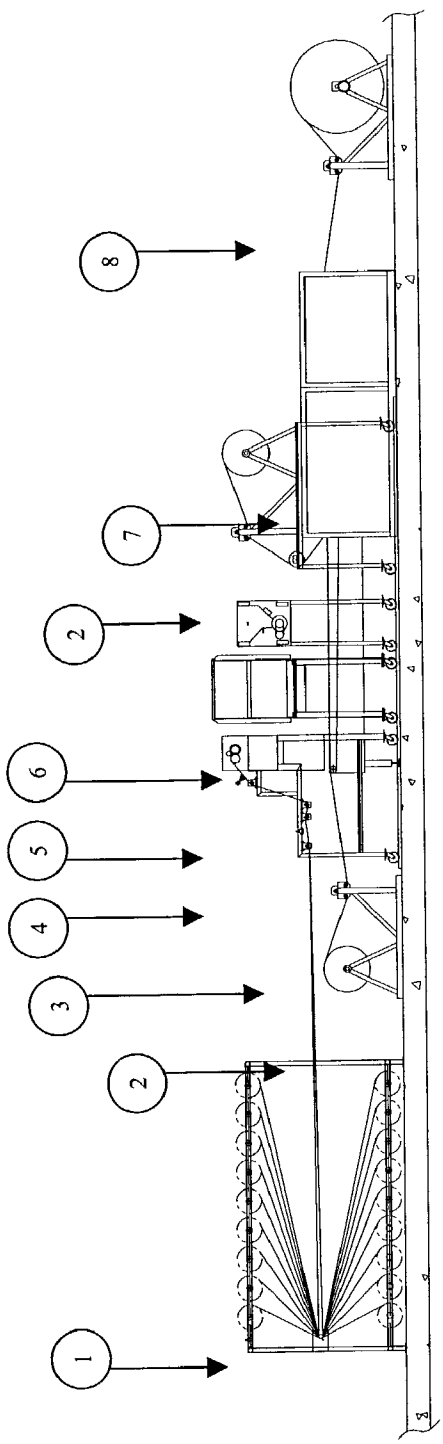
(57) **ABSTRACT**

Methods of randomly dispersing chopped carbon fiber and consolidating the materials together to make a fiber reinforcement mat are disclosed. The term "Z-mat" is used to describe the claimed random fiber mat in which the chopped fibers are not preferentially oriented in either the x or y direction in the in-plane directions of the mat. The stiffness in the Z-mat is substantially independent of the test direction in the plane of the mat. The Z-mat offers the distinct advantages of higher stiffness and lighter weight.



1. Feed Creel
2. Unwinder
3. Spreader
4. Chopper
5. Future Equip.
6. Powder Coater
7. Laminator
8. Winder



1. Feed Creel
2. Unwinder
3. Spreader
4. Chopper
5. Future Equip.
6. Powder Coater
7. Laminator
8. Winder

Figure 1

METHODS OF RANDOMLY DISPERSING CHOPPED CARBON FIBER AND CONSOLIDATING THE MATERIALS TOGETHER TO MAKE A FIBER REINFORCEMENT MAT

RELATED APPLICATIONS

[0001] This application claims priority from Provisional Application Serial No. 60/307,599, filed Jul. 26, 2001, entitled "Methods of Randomly Dispersing Chopped Carbon Fiber and Consolidating the Materials Together to Make a Fiber Reinforcement Mat," the entire disclosure of which is hereby incorporated herein by reference.

FIELD OF INVENTION

[0002] This invention relates to an apparatus and method for random fiber mats. The invention has particular applicability in chopping a carbon tow into strands of shorter lengths and distributing the strands in random orientation.

BACKGROUND

[0003] Various methods have been tried to chop, randomize, and consolidate carbon fiber in random mat format. The primary problems are maximizing randomness of fiber orientation, minimizing variability of mat area weight, and making a product that is easily handled, all of which cause problems with producing an effective reinforcement mat.

SUMMARY OF THE INVENTION

[0004] By combining different fiber spreading techniques with several designs of air flow in an enclosed chute a number of trials have been made to identify the right combination of fiber spread, air flow, and chute geometry to randomly orient carbon fiber chop while maintaining uniform area weight distribution. In addition, several trials have been made with and without various backing materials to improve the overall handling characteristics of the resulting mat.

[0005] In one embodiment, three 48K tows have been successfully chopped and randomly distributed while maintaining a very uniform area weight distribution (up to 230 g/m^2). A powder binder was added and the resulting materials consolidated under heat and pressure to make a 16" wide mat at 23 feet per minute. These values are typical of commercial fiber production. Fiberglass veils have also been added to both sides of the mat to make a hybrid as well.

[0006] Different embodiments of this invention include the following: (1) An equipment that provides a dry, mechanical way to assemble fibers into mat form. (2) A mat in which the randomness of chopped carbon fiber in the mat is maximized while minimizing the variability of the area weight in the product by using air, a distribution bar, and a specific chute design. (3) A mat in which the chopped carbon fiber can be consolidated with fiberglass or polyester veil or scrim to make a fiber hybrid mat. (4) The mat of embodiments (2) and (3) that is easily handled without susceptibility to tear. (5) The mat of embodiments (2) and (3) that is easily wet out providing excellent resin penetration for composite part manufacturing. (6) A glass veil/carbon fiber mat that has a very smooth surface with almost no protruding fibers. (7) Methods of carrying out the embodiments of (1)-(6) above.

[0007] This invention can be used commercially to chop, distribute, and bind carbon fiber with fiberglass veil to make reinforcement mat for composites. It may be incorporated into the carbon fiber production line as an add-on to the sizing section of the line. Or, it may be set up as a separate off line entity to chop, distribute, and bind already produced carbon fiber tows. There are a variety of reasons to use carbon fiber mat; the most important of which is to maximize mechanical properties in all directions. The unique advantage provided by using fiberglass veil as a carrier for the carbon fiber is that it will improve surface finish in products such as automobile and boat paneling.

[0008] As will be realized, this invention is capable of other and different embodiments, and its details are capable of modifications in various obvious respects, all without departing from this invention. Accordingly, the drawings and description are to be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] **FIG. 1** is a view of the process flow diagram of the process for making the chopped fiber mat of this invention.

DETAILED DESCRIPTION

[0010] This invention embodies a chopper system that cuts carbon fiber tow (up to 320 K) into shorter lengths (up to 3") and distributes them in random orientation. It also includes a powder-coater and laminator that consolidates the materials to make a randomly oriented reinforcement mat that minimizes area weight variability and has excellent handling characteristics.

[0011] The invention also includes resulting carbon fiber mats that can be made with the equipment listed, including but not limited to the following:

[0012] (1) Mat made with chopped carbon fiber up to 3" in length bound together with a powder resin and without any backing material.

[0013] (2) Mat made as in item 1 that includes a backing material such as a fiber (i.e. polyester, glass, or the like) veil or scrim or some type of release paper.

[0014] The methods of this invention include some or all of the following steps:

[0015] (1) The chopper chute and air distribution equipment used to lay the carbon fiber on the veil is unique to controlling the area weight distribution and random fiber orientation.

[0016] (2) The spreading process used to open the carbon fiber tow prior to chopping is unique to helping randomize the fiber distribution.

[0017] (3) The consolidation of fiberglass veil and chopped carbon fiber with a powder coating improves the handling, appearance, and mechanical properties of the mat.

[0018] In one embodiment, this invention uses 95% carbon fiber tow from PAN (polyacrylonitrile) made by a continuous carbonization process. This material is then converted into various product forms to the processing of the material. The "Z-mat" process chops the carbon fiber into 1", 2", or 3" lengths and randomly disperses and binds them in mat form. The term "Z-mat" is used to describe the

claimed random fiber mat in which the chopped fibers are not preferentially oriented in either the x or y direction in the in-plane directions of the mat. The Z-mat offers the distinct advantages of higher stiffness and lighter weight.

[0019] The maximum line speed is dependent on the desired area weight of the end product. Essentially the feed rate of carbon fiber, number of tows, and the conveyor speed dictate the resulting area weight. In one embodiment, the line was designed to process a maximum of 150 lb/hr carbon fiber at most all product area weights.

[0020] The details of the process, with reference to **FIG. 1**, are explained below.

[0021] (1) Raw Material Handling:

[0022] (a) Carbon Fiber:

[0023] The feed creel is a steel frame with 36 evenly spaced spool positions. Carbon fiber spools are mounted on each spool position. The creel aligns the fibers as parallel as possible and applies tension as necessary to provide a uniform distribution of fiber to the rest of the process. The required number of ends from the carbon fiber spools is threaded through the guide bars at evenly spaced intervals. Each spool position utilizes a friction brake to sustain adequate tension on the tow as it passes on to the process. Changing the dead weight on the brake varies tension.

[0024] (b) Backing/Support:

[0025] Two unwinders are positioned on the line to allow backing material, preferably, up to 64" wide to be applied to the mat. Backing can be fiberglass veil, fiberglass scrim, release paper or the like. One unwinder is located just after the feed creel at the start of the conveyor belt. This unwinder is used to feed backing to the process that will catch the fiber as it falls from the chopper. The second unwinder is mounted after the chopper and on top of the laminator. This unwinder is used to apply material to the top of the mat just before it enters the laminator. Since the backing will be, preferably, up to 62" wide and can weigh up to 100 lbs., a platform and walkway were provided to allow two people access to this unit.

[0026] Both unwinders control tension using load cells and variable frequency drive motors. The operator will be able to set tension and the system will control it to a minimum +10% of set point. Both unwinders are modular and can be removed when not in use.

[0027] (2) Spreading Process:

[0028] After the creel the carbon fiber is threaded through a series of bars that help spread the fiber. The first bar is a guide bar to maintain tow position coming off the creel. The next bars spread each tow up to 1 5/8" wide. The final bar helps feed the spread fiber to the chopper nip. It is important that fiber alignment be maintained through this process.

[0029] Water mist can be applied to the spread tow just before it leaves the spreading system. The mist is used to keep fly down in the chopping process. However, it does cause the spread tow to narrow a bit as a result of wicking.

[0030] (3) Chopping Process:

[0031] A rotary chopper was used to cut carbon fiber tow into lengths of 1", 2", or 3". The length is adjustable by changing the blade positions on the chopper head. The chopped pieces fall down through an enclosed chute to the conveyor belt where it is taken to the rest of the process. Immediately after the chopper head is a randomizer. The randomizer consists of a stationary roll with several pins extending outward. It is used to break up the fiber bundles as they fall to the conveyor. Also at the top of the chopper is a cot cleaner. This device is a series of air tubes directed at the cot roller that oscillate back and forth. High-pressure air is passed through each tube to help knock off any fiber collecting on the cot. The sides of the chute are adjustable to allow the operator to vary product width up to 60". The chopping and spreading equipment are modular and can be removed when not being used.

[0032] The chute can be made to run under negative pressure by inserting an air laying plate at the bottom. This perforated plate is inserted over top of the conveyor and under the porous backing material. The plate is connected to a filter and fan and draws the chopped fiber down to the backing material. This plate can preferably be used with some type of porous backing passing over it. Without the backing carbon fiber will stick to the plate and not be moved to the rest of the process.

[0033] (4) Coating:

[0034] Preferably, dry coatings could be used with the Z-mat process. A powder coater located just after the chopper module applies these coatings. The powder coater is a large hopper with a rotating roller in the bottom opening. The surface of the roller is roughened enough to pick the powder up from inside the hopper. Outside the hopper, a brush oscillates back and forth on the surface of the roller to knock the powder off. The loosened powder falls through a chute and onto the mat. Adjusting the speed of the roller controls the powder application rate. A level controller is supplied in the hopper that will indicate when it needs to be filled. A platform/walkway is provided around the unit to help with maintenance and material change out. The powder coater is modular so it can be removed when not used.

[0035] (5) Laminating Process:

[0036] The laminator consists of two Teflon belts on top of each other pressed together by a series of nips. A radiant panel to preheat the mat is mounted just prior to the entrance of the laminator. The preheat helps to avoid flashing the coatings which would cause poor adhesion to the fiber. The first half of the laminator is heated up to a maximum 425° F. by elements on top and bottom of the belts. At this point the powder coating and/or the coating on the backing material is melted and flows into the carbon fiber. The second half of the laminator is cooled to 130° F. by coils on top and bottom of the belts that circulate water from a 10-ton chiller. This is where the coating(s) harden back to their dry form, thus freezing the fibers together in mat form. The 10-ton chiller will be mounted outside, adjacent to the line. Pressure, temperature and residence time determine how well the mat is fused together. The belt speed and type of powder coating and/or type of coating on the backing material dictate the laminator temperature set points. Four-limit switches and pneumatic controls monitor the edges of

the mat to make sure the product doesn't walk more than +1 inch. The opening through the laminator can be manually adjusted from 0-1" wide depending on the desired product thickness. The product is pulled off of the belts as it exits the laminator. Any material left sticking to the belt is wiped off by circulating cleaning rolls. The material knocked off the belts is collected in receptacle trays that must be cleaned out routinely.

[0037] (6) Winding:

[0038] The winder spools the product exiting the laminator under controlled tension. Load cells and a variable frequency drive motor could be used to control tension. The operator sets the desired tension on the product. The product can be spooled up to 18" diameter. The final width of the product is determined by how wide the operator sets the edge cutters. The edge cutters are designed to remove excess material from the product as necessary. When the desired length is reached the operator must manually cut the material. The final product is placed on a cart for testing, if required, and packaging.

[0039] (7) Electrical & Controls:

[0040] All equipment, except the chiller, would preferably be controlled at the man-machine interface (MMI) mounted on the feed creel. The MMI will have all necessary settings fully adjustable by the operator. Certain functions associated with maintenance and engineering should preferably be accessible by key switch. The chiller should preferably have its own control panel mounted on one of the electrical control cabinets next to the end of the Z-mat line. Receptacles will be located above the line to provide power to all modular equipment. All other equipment could be hard-wired.

[0041] Samples made by the Z-mat Process

[0042] (1) PANEX® 33 ZM

[0043] PANEX® 33 ZM is a chopped carbon fiber mat manufactured from PANEX® 33 continuous tow that is made from polyacrylonitrile (PAN) precursor. PANEX® 33 ZM chopped carbon fibers are available with a variety of sizing and/or binder formats for different composite processing methods and for compatibility with a wide range of standard resin systems.

TABLE 1

Typical Fiber Properties of PANEX ® 33 ZM

	U.S. Units	SI Units
Tensile Strength*	550 Ksi	3800 Mpa
Tensile Modulus*	33 Msi	228 GPa
Electrical Resistivity	0.00068 ohm-in	0.00172 ohm-cm
Density	0.065 lb/in^3	1.81 g/cc
Fiber Diameter	0.283 mils	7.2 microns
Carbon Content	95%	95%

*(Tow Tensile Test)

[0044]

TABLE 2

Typical Laminate Properties of PANEX ® 33 ZM[1]
(At 40% w/w carbon content)

Resin Type	Tensile Strength: ksi(MPa)	Tensile Modulus: $\times 10^6$ psi (GPa)	Test Method	Flexural Strength: ksi(MPa)	Flexural Modulus: ksi(MPa)	Test Method
Polyester*	23.4 (161)	2.45 (16.9)	ASTM D638	38.6 (266)	2.43 (16.8)	ASTM D790
Vinyl Ester**	25.7 (177)	2.51 (17.3)	ASTM D638	37.2 (256)	2.61 (24.9)	ASTM D790
Polyurethane***	27.2 (188)	3.22 (22.2)	ASTM D638	32.6 (225)	2.43 (16.8)	ASTM D790

[1]Properties based on 2" CF at 150 g/m^2 with
*AOC F11-2001
**Dow Derakane 470
***Dow Ispolast 301

[0045] The chopped fiber mat PANEX® 33 ZM has several variations as shown in the accompanying selector chart for sizing format, resin compatibility, and packaging information.

[0046] PANEX® 33 ZM chopped carbon fiber mat was made with our copolyester sizing on the fibers and a polyester powder binder holding the mat together. PANEX® 33 ZM products are defined by our nine-digit product code which is detailed below.

Nine Digit Format Code

1st Digit (Backing)	2nd & 3rd Digits (Mat Width)	4th Digit (CF Length)	5th Digit (CF Area Weight)
O-None	00-Custom	1-1"	0-Custom
C-Custom	12-12	2-2"	1-100 g/m^2
V-Fiberglase Veil	24-24"	3-3"	2-150 g/m^2
T-Thermoplastic Veil	36-36"	X-Custom	3-200 g/m^2
P-Thermoplastic Scrim	48-48"		4-250 g/m^2
S-Fiberglass Scrim	60-60"		5-300 g/m^2
F-Thermoplastic Film			

6th Digit (Sizing Type)	7th Digit (% Sizing)	
0-None	0	0.0
1-Epoxy	1	0.55 ± 0.25
2-Polyester	2	1.0 ± 0.25

-continued

Nine Digit Format Code		
3-Polyester (Styrene Soluble)	3	1.5 ± 0.25
4-Polypropylene	4	2.0 ± 0.5
	5	3.0 ± 0.5
	6	4.0 ± 1.0
	7	6.0 ± 1.0
	8	8.0 ± 1.0
X-Custom	9	>9.0
8th Digit (Binder Type)	9th Digit (% Binder)	

TABLE 2

Typical Fiber Properties of PANEX ® 33 ZM

	U.S. Units	SI Units
Tensile Strength*	550 Ksi	3800 Mpa
Tensile Modulus*	33 Msi	228 GPa
Electrical Resistivity	0.00068 ohm-in	0.00172 ohm-cm
Density	0.065 lb/in^3	1.81 g/cc
Fiber Diameter	0.283 mils	7.2 microns
Carbon Content	95%	95%

*(Tow Tensile Test)

[0049]

TABLE 4

Typical Laminate Properties of PANEX ® 33 ZM-V
(At 40% w/w carbon content)

Resin Type	Tensile Strength: ksi(MPa)	Tensile Modulus: ×10^6 psi (GPa)	Test Method	Flexural Strength: ksi(MPa)	Flexural Modulus: ksi(MPa)	Test Method
Polyester*	24.1 (166)	2.48 (17.1)	ASTM D638	39.2 (270)	2.40 (16.5)	ASTM D790
Vinyl Ester**	24.6 (170)	2.42 (16.7)	ASTM D638	35.6 (245)	2.65 (18.3)	ASTM D790
Polyurethane***	25.2 (174)	2.81 (19.4)	ASTM D638	30.4 (210)	2.39 (16.5)	ASTM D790

*AOC F11-2001
**Dow Derakane 470
***Dow Ispolast 301

-continued

Nine Digit Format Code		
0-None	0	0.0
1-Epoxy Powder	1	1.0 ± 0.5
2-Polyester Powder	2	2.0 ± 0.5
3-Polyester Powder (Styrene Soluble)	3	3.0 ± 0.5
4-Thermoplastic Fiber	4	4.0 ± 0.5
	5	6.0 ± 1.0
	6	8.0 ± 1.0
	7	9.0 ± 1.0
	8	>10.0
X - Custom		

[0047] (2) PANEX® 33 ZM-V

[0048] PANEX® 33 ZM-V is a chopped carbon fiber mat manufactured from PANEX® 33 continuous tow that is made from polyacrylonitrile (PAN) precursor. PANEX® 33 carbon fibers are available with a variety of sizing and/or binder formats for different composite processing methods and for compatibility with a wide range of standard resin systems. ZM-V is a randomly oriented chopped strand mat product composed of specified lengths (1", 2" or 3") of carbon fiber sandwiched between layers of polymer or fiberglass veil.

[0050] The chopped fiber mat PANEX® 33 ZM-V has several variations as shown in the accompanying selector chart for sizing format, resin compatibility, and packaging information. PANEX® 33 ZM-V chopped carbon fiber mat was made using copolyester sizing on the fibers and a polyester binder holding the mat together. PANEX® 33 ZM-V products can be made in many different widths and fiber area weights. PANEX® 33 ZM-V was made in product weights of 100, 150, 200, 250 and 300 g/m^2 and widths of 61 cm (24 in), 91 cm (36 in), 122 cm (48 in), and 152 cm (60 in). The process of this invention also makes other widths and area weights. The mat binder and carbon fiber sizing used are as follows:

Mat Binders	Wt. % Binder	Carbon Fiber Sizing	Wt. % Sizing
Epoxy	3–7	Epoxy	0.55–2
Polyester	3–7	Polyester	0.55–2
Polypropylene	3–7	Polypropylene	0.55–2
Polymer Fibers	3–7	Copolyester	0.55–2

[0051] Typically, the polyester is soluble styrene. The different types of backing used are: (1) Fiberglass Veil; (2) Thermoplastic Veil and (3) Thermoplastic Film.

[0052] The above description is presented to enable a person skilled in the art to make and use the invention, and is provided in the context of a particular application and its

requirements. Various modifications to the preferred embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the invention. Thus, this invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

[0053] This application discloses several numerical range limitations. Persons skilled in the art would recognize that the numerical ranges disclosed inherently support any range within the disclosed numerical ranges even though a precise range limitation is not stated verbatim in the specification because this invention can be practiced throughout the disclosed numerical ranges. A holding to the contrary would "let form triumph over substance" and allow the written description requirement to eviscerate claims that might be narrowed during prosecution simply because the applicants broadly disclose in this application but then might narrow their claims during prosecution. Finally, the entire disclosure of the patents and publications referred in this application are hereby incorporated herein by reference.

1. An apparatus for producing a chopped fiber mat, comprising a tow spreader for spreading a fiber tow prior to a chopper that chops said fiber tow into chopped fiber bundles, and a randomizer that breaks up the chopped fiber bundles to produce fibers having a random orientation in a direction in the plane of the chopped fiber mat.

2. The apparatus of claim 1, wherein the chopped fiber mat has a stiffness that is substantially independent of a test direction in the plane of the chopped fiber mat.

3. The apparatus of claim 2, wherein the chopped fiber mat has a ratio of a maximum-in-plane stiffness to a minimum-in-plane stiffness of 1.3.

4. The apparatus of claim 2, wherein the chopped fiber mat has a ratio of a maximum-in-plane stiffness to a minimum-in-plane stiffness of 1.2.

5. The apparatus of claim 2, wherein the chopped fiber mat has a ratio of a maximum-in-plane stiffness to a minimum-in-plane stiffness of 1.1.

6. The apparatus of claim 1, wherein the fiber tow is a carbon fiber tow.

7. The apparatus of claim 1, wherein the chopped fiber mat further comprises a backing.

8. The apparatus of claim 7, wherein the backing is selected from the group consisting of a fiberglass veil, a thermoplastic veil, a thermoplastic scrim, a fiberglass scrim, a thermoplastic film, and combinations thereof.

9. The apparatus of claim 1, wherein the fiber tow comprises a sizing and the chopped fiber mat comprises a powder binder.

10. The apparatus of claim 8, wherein the sizing is a polyester-containing sizing and the powder binder is a polyester powder binder.

11. A method for producing a chopped fiber mat, comprising spreading a fiber tow, chopping the fiber tow to produce chopped fiber bundles and breaking up the chopped fiber bundles to produce fibers having a random orientation in a direction in the plane of the chopped fiber mat.

12. The method of claim 11, wherein the chopped fiber mat has a stiffness that is substantially independent of a test direction in the plane of the chopped fiber mat.

13. The method of claim 12, wherein the chopped fiber mat has a ratio of a maximum-in-plane stiffness to a minimum-in-plane stiffness of 1.3.

14. The method of claim 12, wherein the chopped fiber mat has a ratio of a maximum-in-plane stiffness to a minimum-in-plane stiffness of 1.2.

15. The method of claim 12, wherein the chopped fiber mat has a ratio of a maximum-in-plane stiffness to a minimum-in-plane stiffness of 1.1.

16. The method of claim 11, wherein the fiber tow is a carbon fiber tow.

17. The method of claim 11, wherein the chopped fiber mat further comprises a backing.

18. The method of claim 17, wherein the backing is selected from the group consisting of a fiberglass veil, a thermoplastic veil, a thermoplastic scrim, a fiberglass scrim, a thermoplastic film, and combinations thereof.

19. The method of claim 11, wherein the fiber tow comprises a sizing and the chopped fiber mat comprises a binder.

20. The method of claim 19, wherein the sizing is selected from the group consisting of a thermosetting sizing, a thermoplastic sizing, and combinations thereof.

21. The method of claim 20, wherein the thermosetting sizing is selected from the group consisting of an epoxy-containing sizing and a polyester-containing sizing.

22. The method of claim 20, wherein the thermoplastic sizing is selected from the group consisting of a polypropylene-containing sizing and a polyethylene-containing sizing.

23. The method of claim 19, wherein the binder is selected from the group consisting of a thermosetting binder, a thermoplastic binder, and combinations thereof.

24. The method of claim 23, wherein the thermosetting binder is selected from the group consisting of an epoxy-containing binder and a polyester-containing binder.

25. The method of claim 23, wherein the thermoplastic binder is selected from the group consisting of a polypropylene-containing binder and a polyethylene-containing binder.

26. The method of claim 23, wherein the thermoplastic binder is selected from the group consisting of a powder-containing binder and a fiber-containing binder.

* * * * *