REINFORCED STRUCTURAL MEMBER AND METHOD OF FORMING

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ABSTRACT

A new and useful structure and method for reinforcing a structural member is provided. A fabric cover on a selected portion of the structural member, wherein (a) the fabric cover comprises a plurality of different carbon fiber types in a predetermined configuration, (b) each of the different carbon fiber types has a different modulus of elasticity than the other carbon fiber types, and each of the different carbon fiber types being of a type and in an orientation such that it will carry at least a part of an impact load due to pressure wave impact, inertia loading due to ground motion forces, and combinations of the foregoing, and (c) the predetermined configuration and the different modulus of elasticity of the different carbon fiber types designed to react to energy from forces due to pressure wave impacts, inertia loading due to ground motion forces, and combinations of the foregoing, in a manner such that higher modulus carbon fiber types will fracture before lower modulus carbon fiber types, so that in dissipating the energy of the impact load when the higher modulus carbon fibers break, the lower modulus carbon fiber types.
REINFORCED STRUCTURAL MEMBER AND METHOD OF FORMING

BACKGROUND AND SUMMARY

[0001] The present invention relates to a reinforced structural member and to a method of reinforcing a structural member, in a manner designed to strengthen the structural member and to dissipate energy from forces due to pressure wave impacts (explosion), or inertia loading (earthquake) due to ground motion forces.

[0002] In an earlier application of the applicant, Ser. No. 10/307,745, a reinforced structural member and a method of reinforcing the structural member are provided, that are believed to be effective to strengthen the structural member and to dissipate energy from forces due to pressure wave impacts (explosion), or inertia loading (earthquake) due to ground motion forces.

[0003] The present invention is designed to build on the concepts of application Ser. No. 10/307,745, and to provide additional new and useful features which are particularly useful in providing structure and method that can be retrofit to an existing structural member to enable the structural member to improve the energy dissipation capabilities of the structural member when subjected to pressure wave impacts (e.g., pressure waves due to an explosion) or to ground motion force transfer (e.g., due to inertia forces generated from ground motion, e.g., earthquake).

[0004] The principles of the present invention are particularly useful in providing energy dissipation for a structural member formed, e.g., of steel, concrete, brick, wood, masonry, and combinations of the foregoing.

[0005] According to the present invention, a reinforced structural member comprises a structural member and a fabric or laminate cover on a selected portion of the structural member; wherein

[0006] a. the fabric cover comprises a plurality of different carbon fiber types in a predetermined configuration (so that the fabric cover basically is formed essentially from carbon fibers),

[0007] b. each of the different carbon fiber types has a different modulus of elasticity than the other carbon fiber types, and each of the different carbon fiber types being of a type and in an orientation such that it will carry at least a part of an impact load due to pressure wave impact, inertia loading due to ground motion forces, and combinations of the foregoing, and

[0008] c. the predetermined configuration and the different modulus of elasticity of the different carbon fiber types designed to react to energy from forces due to pressure wave impacts, inertia loading due to ground motion forces, and combinations of the foregoing, in a manner such that higher modulus carbon fiber types will fracture before lower modulus carbon fiber types, so that in dissipating the energy of the impact load when the higher modulus carbon fibers break, the lower modulus carbon fiber types will remain intact to keep the reinforced structural member together.

[0009] The fabric or laminate cover preferably comprises at least two different types of carbon fibers, each of which has a different modulus of elasticity than the other carbon fiber types, and each carbon fiber type being in a pattern such that when subjected to energy from impact loads due to pressure wave impacts (e.g., due to an explosion), inertia loading due to ground motion forces, and combinations of the foregoing, (i) the carbon fiber type with the highest modulus of elasticity will fracture first (thereby dissipating a portion of the energy of the impact load), (ii) the carbon fiber type with the next highest modulus of elasticity will fracture next (thereby dissipating additional energy of the impact load), and (iii) resulting in the lower modulus carbon fiber types being in a state where they should be able to absorb the remaining energy of the impact load, and the likelihood of fracture of the carbon fiber type with the lowest modulus of elasticity is minimized. All three or more types of carbon fibers can be parallel or perpendicular to one another.

[0010] In addition, according to the preferred embodiment, the fabric cover comprises (i) first type of carbon fibers having a minimum modulus of elasticity of 90 Msi, (ii) second type of carbon fibers with a minimum modulus of elasticity of 60 Msi, and (iii) third type of carbon fibers with a minimum modulus of elasticity of 30 Msi. Moreover, the fabric cover preferably includes a woven fabric formed from at least the first, second and third types of carbon fibers, and the woven fabric includes (i) a first orientation of carbon fibers in which carbon fibers of each of the first, second, and third types extend parallel to each other, and (ii) a second orientation of carbon fibers in which carbon fibers of each of the first, second and third types extend transverse to the first orientation of carbon fibers. Also, the fabric cover is preferably formed from plural layers of the woven fabric that are applied to both sides of the structural member.

[0011] The principles of the present invention are particularly useful in providing energy dissipation for a structural member formed, e.g., of steel, concrete, brick, wood, masonry, and combinations of the foregoing.

[0012] Further aspects of the present invention will become apparent from the following detailed description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 is a schematic illustration of a structural member reinforced with a fabric cover, according to the principles of the present invention;

[0014] FIG. 2 is a schematic illustration of a preferred woven fabric pattern that is used to form a woven fabric for use as a fabric cover (and which can also be used in a laminate that forms the fabric cover), according to the principles of the present invention; and

[0015] FIG. 3 is a schematic illustration of the manner in which a fabric cover can be formed on a structural member (also referred to as a substrate) with fabric layers that are different than the layers of FIG. 2, but also according to the principles of the present invention.

DETAILED DESCRIPTION

[0016] As described above, the present invention relates to a reinforced structural member, and to a method of reinforcing a structural member, in a manner that dissipates energy from impact loads due to pressure wave impact (e.g., due to an explosion), or inertia loading (e.g., due to ground motion...
forces due to an earthquake). The principles of the invention are described below in connection with structural reinforcement of a beam or wall. However, from that description, the manner in which the principles of the present invention can be used to reinforce various other types of structural members will be apparent to those in the art.

[0017] As illustrated in the Figures, a structural member 100 comprises a beam, column, slab or wall and, etc. that can be formed of metal, concrete, wood, or other materials that are designed to be support structures. The structural member 100 comprises sides 100a, 100b, and a fabric cover 102, according to the principles of the present invention, is applied to each of the opposite sides of the structural member. The fabric cover 102 can comprise a plurality of layers of woven carbon fiber fabric that are applied to the structural member, and can also comprise a laminate, or several laminates that are applied to the structural member (in this application, reference to a “laminate” means a preformed structure made of carbon fiber fabric layers that are bonded together, e.g., by a manufacturing process by which epoxy impregnates the carbon fibers). For example, in the illustrated example, the fabric cover 102 comprises a plurality of woven carbon fiber fabric layers 104, 106, 108, that are bonded to the opposite sides of the structural member (or to each other) by epoxy resin.

[0018] Each of the woven fabric layers 104, 106, 108, is preferably woven from at least two different carbon fiber types, each of which has a different modulus of elasticity than the other carbon fiber types. Thus, each of the woven fabric layers is essentially formed from carbon fibers. Moreover, each of the different carbon fiber types is of a type and in an orientation such that it will carry at least a part of an impact load due to pressure wave impact, inertia loading due to ground motion forces, and combinations of the foregoing. In this application, reference to carbon fiber types designed to carry at least a part of an impact load means that the modulus of elasticity of the carbon fiber with the lowest modulus of elasticity is preferably at least equal to the modulus of elasticity of the structural member, or no more than 20% less than the modulus of elasticity of the structural member.

[0019] The woven fabric with carbon fibers of different modulus of elasticity is designed to enable the carbon fibers to react to energy from impact loads due to pressure wave impacts, inertia loading due to ground motion forces, and combinations of the foregoing, in a manner such that higher modulus carbon fiber types will fracture before lower modulus carbon fiber types, so that in dissipating the energy of the impact load when the higher modulus carbon fibers break, they dissipate portions of the impact loads, and the lower modulus carbon fiber types (which have modulus of elasticity at least equal to, or no more than 20% less than, the modulus of elasticity of the structural member). Thus, as the higher modulus carbon fibers absorb impact loads and break, as described below, the lower modulus carbon fibers will remain intact to keep the reinforced structural member together.

[0020] Each of the woven fabrics 104, 106, 108 is preferably formed of at least three different types of carbon fibers, including (i) first type of carbon fibers 110 having a minimum modulus of elasticity of 90 MSI, (ii) second type of carbon fibers 112 with a minimum modulus of elasticity of 60 MSI, and (iii) third type of carbon fibers 114 with a minimum modulus of elasticity of 30 MSI. More preferably, the first, second and third types of carbon fibers 110, 112, 114 each have a raw fiber tensile strength of at least 500 KSI, and each of the first second and third types of fibers forms about ⅓ of the fiber used to form the fabric cover. Thus, there are about equal amounts of the different types of carbon fibers in the fabric cover.

[0021] In addition, as seen from FIG. 2, in each woven fabric 104, 106, 108, the first, second and third types of carbon fibers 110, 112, 114 are in a pattern characterized by (i) a first orientation of fibers in which fibers of the first, second, and third types of carbon fibers extend parallel to each other, and (ii) a second orientation of fibers in which fibers of the first, second and third types of carbon fibers extend transverse to the first orientation of fibers. In this application, reference to one carbon fiber being oriented “transverse” to another carbon fiber is intended to mean that the one carbon fiber is not oriented parallel to the other carbon fiber, but either crosses the other carbon fiber, or is oriented such that projections of the carbon fibers would cross each other. Thus, the carbon fibers do not have to extend in horizontal and vertical rows, as illustrated, but rather can be in different patterns, such that their energy dissipation characteristics are tuned to the particularly type(s) of energy loading of the structural member that the fabric cover is intended to dissipate.

[0022] Also, as seen from FIG. 1, a fabric cover 102 is applied to each of the opposite sides of the structural member 100, and the fabric cover applied to each of the opposite sides preferably comprises a plurality of woven fabrics 104, 106, 108, each woven fabric having three different types of carbon fibers 110, 112, 114, in the woven pattern shown in FIG. 3 and described above. Also, the fabric cover can be formed by one or more laminates of woven carbon fiber fabric segments, each laminate formed from the different types of carbon fibers.

[0023] Still further, the woven fabrics 104, 106, 108 are applied to the structural member by epoxy that is characterized by the following mechanical properties: elongation at failure 5%; tensile strength 25,000 psi. The woven fabric 104 adjacent the structural member is secured to the structural member by epoxy, and the other woven fabrics 106, 108 are secured to the woven fabric 104 or to each other by epoxy.

[0024] The fabric cover 102 preferably comprises at least two (and more preferably three) different types of carbon fibers, each of which has a different modulus of elasticity than the other carbon fiber types, and each carbon fiber type being in a pattern such that when subjected to energy from impact loads due to pressure wave impacts (e.g., due to an explosion), inertia loading due to ground motion forces, and combinations of the foregoing, (i) the carbon fiber type with the highest modulus of elasticity will fracture first (thereby dissipating a portion of the energy of the impact load), (ii) the carbon fiber type with the next highest modulus of elasticity will fracture next (thereby dissipating additional energy of the impact load), and (iii) resulting in the lower modulus carbon fiber types being in a state where they should be able to absorb the remaining energy of the impact load, and the likelihood of fracture of the carbon fiber type with the lowest modulus of elasticity is minimized. When
the higher modulus carbon fibers break, they release the energy that was stored in them. When the woven carbon fiber fabric is bonded to the structural member (e.g., a beam or wall), it acts as a structural element and shares the load that is imparted on the structural member. This means that the original structural member will have to resist less load. This load, in turn, is stored in the woven carbon fiber fabric as an energy which is then released upon fracture of the carbon fibers with higher modulus of elasticity.

[0025] Also, the epoxy that bonds the carbon fiber layers to the structural member or to the other carbon fiber layers serves to transmit impact load forces between the carbon fiber layers and the structural member so that the carbon fibers can dissipate the impact load in the manner described above. When the woven carbon fiber layers are of the three different types of carbon fiber that is shown and described in connection with FIG. 2, the woven carbon fiber layers would preferably be bonded to the structural member and to each other by a epoxy.

[0026] While it is preferred that the fabric cover 102 is formed of layers of the woven fabric 104, 106, 108, each with the three different types of carbon fibers, it is also contemplated that each of the layers of fabric could be of a single type of the carbon fibers. FIG. 3 schematically illustrates the manner in which such a fabric cover would be formed. Initially, an epoxy is applied to the structural member (substrate). An initial layer of fabric 120 formed solely from the lower modulus carbon fiber would be initially applied and bonded to each side of the structural member by epoxy. Next, a layer of fabric 122 formed from the next lowest modulus would be applied and bonded to the first layer by epoxy. Next, the highest modulus carbon fiber 124 would be applied and bonded to the second layer by epoxy.

[0027] As described above, the fabric cover according to the present invention is primarily characterized by its ability to effectively dissipate impact loads that are directed at the structural member. Additional benefits of a fabric cover of the present invention include:

[0028] a. A fabric cover formed exclusively from carbon fiber provides a non-corrosive material that will not degrade when exposed to moisture, chemicals between pH2-12.5, and environmental effects like UV.

[0029] b. A fabric cover formed exclusively from carbon fiber allows for greatest amount of strength per ply to decrease the weight and thickness of the system (i.e. the total amount of material applied to the structural member).

[0030] c. A fabric cover formed exclusively from carbon fiber and applied to the structural member by epoxy should be capable of catching fragmentations, shrapnel, and falling debris that often accompany an impact load

[0031] d. The system (i.e. the all carbon fabric cover and epoxy) does not combust when exposed to a fire bullet

[0032] e. The system does not delaminate or crack away from the substrate

[0033] When the different types of carbon fibers are woven into the pattern shown and described in connection with FIG. 2, the woven carbon fabric can be formed by weaving or stitching the different types of carbon fibers in a desired pattern, using conventional weaving or stitching, or other known fabric forming techniques. In addition, with individual layers of the different carbon fiber, as shown and described in connection with FIG. 3, each individual carbon fiber layer can also be formed as a woven fabric formed by weaving or stitching the carbon fibers in a desired pattern, using conventional weaving or stitching, or other known fabric forming techniques. When the woven carbon fibers are formed into a laminate, layers of the woven carbon fiber fabric (where each layer comprises a woven fabric formed of all of the different carbon fibers, or where each layer comprises a woven fabric formed of a different one of the different types of carbon fibers).

[0034] In addition, the particular pattern of the carbon fibers in the any woven carbon fiber fabric can also be predetermined in accordance with the particular energy dissipation characteristics that are desired to be incorporated into the woven carbon fabric. For example, with the woven carbon fabric formed from three different types of carbon fibers (e.g. as shown in FIG. 2) it may be desirable to orient the higher and lower modulus carbon fibers at angles designed to dissipate energy in particular directions, in accordance with the principles of the present invention. Furthermore, it will be apparent to those in the art that for some applications, it will be useful to construct a woven carbon fiber fabric with the different types of carbon fibers oriented in the same direction, with practically no transverse fibers.

[0035] Moreover, while the foregoing description relates to carbon fibers of the preferred moduli of elasticity described above, it is contemplated that carbon fibers of still other moduli of elasticity may also be used, according to the particular energy dissipation characteristics desired for the particular structure the carbon fiber fabric is designed to reinforce.

[0036] Also, while the principles of the invention are described above in connection with a structural member formed e.g. of steel, concrete, wood, masonry, combinations of the foregoing, those principles can also be applied to other types of structural members that can be subjected to impact loads such as pressure wave impact (e.g. due to an explosion), inertia loading (e.g. due to ground motion forces due to an earthquake), and combinations of the foregoing.

[0037] Accordingly, the foregoing detailed description provides a way to reinforce a structural member to provide new and useful energy dissipation capabilities to the structural member. With the foregoing disclosure in mind, the manner in which the principles of the present invention can be applied to providing energy dissipation capabilities to various types of structural members will be apparent to those in the art.

1. A reinforced structural member comprising a structural member and a fabric cover on a selected portion of the structural member; wherein

   a. the fabric cover comprises a plurality of different carbon fiber types in a predetermined configuration,

   b. each of the different carbon fiber types has a different modulus of elasticity than the other carbon fiber types,

   and each of the different carbon fiber types being of a
type and in an orientation such that it will carry at least a part of an impact load due to pressure wave impact, inertia loading due to ground motion forces, and combinations of the foregoing, and

c. the predetermined configuration and the different modulus of elasticity of the different carbon fiber types designed to react to energy from forces due to pressure wave impacts, inertia loading due to ground motion forces, and combinations of the foregoing, in a manner such that higher modulus carbon fiber types will fracture before lower modulus carbon fiber types, so that in dissipating the energy of the impact load when the higher modulus carbon fibers break, the lower modulus carbon fiber will remain intact to keep the reinforced structural member together.

2. A reinforced structural member as defined in claim 1, wherein the fabric cover comprises at least two different types of carbon fibers, each of which has a different modulus of elasticity than the other carbon fiber types, and each carbon fiber type being in a pattern such that when subjected to energy from forces due to pressure wave impacts, inertia loading due to ground motion forces, and combinations of the foregoing, the carbon fiber type with the highest modulus of elasticity will fracture first, and the carbon fiber type with the next highest modulus of elasticity will fracture next, so that in dissipating the energy of the impact load when the higher modulus carbon fibers break, the lower modulus carbon fiber types should be able to carry the remaining impact loads, and the likelihood of fracture of the carbon fiber type with the lowest modulus of elasticity is minimized.

3. A reinforced structural member as defined in claim 2, wherein the fabric cover comprises (i) first type of carbon fibers having a minimum modulus of elasticity of 90 MSI, (ii) second type of carbon fibers with a minimum modulus of elasticity of 60 MSI, and (iii) third type of carbon fibers with a minimum modulus of elasticity of 30 MSI.

4. A reinforced structural member as defined in claim 3, wherein the first, second and third types of carbon fibers each have a raw fiber tensile strength of at least 500 KSI, and each of the first second and third types of fibers forms about ½ d of the fiber used to form the fabric cover.

5. A reinforced structural member as defined in claim 4, wherein the fabric cover includes a woven fabric that includes at least the first, second and third types of carbon fibers defined in claim 4.

6. A reinforced structural member as defined in claim 5, wherein the woven fabric includes (i) a first orientation of fibers in which fibers of the first, second, and third types of carbon fibers extend parallel to each other, and (ii) a second orientation of fibers in which fibers of the first, second and third types of carbon fibers extend transverse to the first orientation of fibers.

7. A reinforced structural member as defined in claim 6, wherein the structural member has opposite sides and a fabric cover is applied to each of the opposite sides of the structural member, and wherein the cover applied to each of the opposite sides comprises a plurality of layers of woven fabric, each layer of woven fabric having the structure of claim 6.

8. A reinforced structural member as defined in claim 7, wherein the fabric cover is bonded by epoxy to each of the opposite sides of the structural member.

9. A reinforced structural member as defined in claim 3, wherein the fabric cover includes a woven fabric that includes at least the first, second and third types of carbon fibers defined in claim 3.

10. A reinforced structural member as defined in claim 9, wherein the woven fabric includes (i) a first orientation of fibers in which fibers of the first, second, and third types of carbon fibers extend parallel to each other, and (ii) a second orientation of fibers in which fibers of the first, second and third types of carbon fibers extend transverse to the first orientation of fibers.

11. A reinforced structural member as defined in claim 10, wherein the structural member has opposite sides and a fabric cover is applied to each of the opposite sides of the structural member, and wherein the cover applied to each of the opposite sides comprises a plurality of layers of woven fabric, each layer of woven fabric having the structure of claim 10.

12. A reinforced structural member as defined in claim 11, wherein the fabric cover is bonded by epoxy to each of the opposite sides of the structural member.

13. A method of reinforcing a structural member comprising the steps of

(a) providing a woven fabric cover comprising a plurality of different carbon fiber types woven into a predetermined configuration, each of the different carbon fiber types having a different modulus of elasticity than the other carbon fiber types, and each of the different carbon fiber types being of a type and in an orientation such that it will carry at least a part of an impact load due to pressure wave impact, inertia loading due to ground motion forces, and combinations of the foregoing, and the predetermined configuration and the different modulus of elasticity of the different carbon fiber types designed to react to energy from forces due to pressure wave impacts, inertia loading due to ground motion forces, and combinations of the foregoing, in a manner such that higher modulus carbon fiber types will fracture before lower modulus carbon fiber types, so that in dissipating the energy of the impact load when the higher modulus carbon fibers break, the lower modulus carbon fiber types should be able to remain intact to keep the reinforced structural member together, and

(b) applying the woven fabric to the structural member in a predetermined fashion that orients the different types of carbon fibers to cause them to react to energy from forces due to pressure wave impacts, inertia loading due to ground motion forces, and combinations of the foregoing, in a manner such that higher modulus carbon fiber types will fracture before lower modulus carbon fiber types, so that in dissipating the energy of the impact load when the higher modulus carbon fibers break, the lower modulus carbon fiber types should remain intact to keep the reinforced structural member together.

14. A method as defined in claim 13, wherein the fabric cover comprises at least two different types of carbon fibers, each of which has a different modulus of elasticity than the other carbon fiber types, and each carbon fiber type being in a pattern such that when subjected to energy from forces due
to pressure wave impacts, inertia loading due to ground motion forces, and combinations of the foregoing, the carbon fiber type with the highest modulus of elasticity will fracture first, and the carbon fiber type with the next highest modulus of elasticity will fracture next, so that in dissipating the energy of the impact load when the higher modulus carbon fibers break, the lower modulus carbon fiber types should be able to carry the remaining impact loads, and the likelihood of fracture of the carbon fiber type with the lowest modulus of elasticity is minimized.

15. A reinforced structural member as defined in claim 14, wherein the fabric cover comprises (i) first type of carbon fibers having a minimum modulus of elasticity of 90 MSL, (ii) second type of carbon fibers with a minimum modulus of elasticity of 60 MSL, and (iii) third type of carbon fibers with a minimum modulus of elasticity of 30 MSL.

16. A method as defined in claim 15, including the step of bonding the fabric cover by epoxy to the structural member.