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(54) Title: REINFORCEMENT FIBERS AND METHODS OF MAKING AND USING SAME

(57) Abstract: Modified fibers that are texturized fibers coated with resin(s) are disclosed. The invention also discloses structural materials reinforced with the modified fibers including concrete, grout and wallboard products. Concrete products and dry concrete mixes contain cement, resin coated (epoxy, acrylic and so on) coated carbon fibers, and any optional components such as silica fumes, slag, stone, sand, and/or other aggregates. The resin coated carbon fibers have a length of about 1 inch to about 6 inches. A method of reinforcing concrete comprises mixing the cement, the acrylic coated carbon fibers, any optional components (such as silica fumes, slag, stone, sand, and/or other aggregates), and water to form a cement slurry, and letting the slurry set to cure the cement and form bonds between the cement and the carbon fibers, thereby obtaining reinforced concrete are also disclosed.



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REINFORCEMENT FIBERS AND METHODS OF MAKING AND USING SAME

5 This application is a continuation-in-part of prior international patent Application No. PCT/US2005/005175, filed February 18, 2005, U.S. Patent Application No. 11/356,720, filed February 17, 2006, U.S. Patent Application No. 11/061,123, filed February 18, 2005, and U.S. Patent Application No. 10/962,187, filed October 7, 2004, which claims the benefit of U.S. Provisional Application No. 60/509,602, filed October 7, 2003, and the text of applications
10 PCT/US2005/005175, 11/356,720, 11/061,123, 10/962,187 and 60/509,602 is incorporated by reference in its entirety herewith.

FIELD OF THE INVENTION

15 This invention relates to modified fibers, and more particularly to texturized fibers coated with resin(s). The invention also relates to structural materials reinforced with the modified fibers including concrete products.

BACKGROUND OF THE INVENTION

20 The use of various fiber materials such as carbon, nylon, fiber glass, E-glass, kevlar for structural applications in place of or in addition to steel and other metals is well known in the art. Some of the properties of the fibers that are often considered for structural applications are tensile strength, tensile modulus, density and specific strength. The superior properties of fibers to steel in terms of their tensile strength, density and specific strength meant that the aerospace construction and consumer industries were obvious markets for these fibers and
25 their composite materials. Carbon and other artificial fibers have replaced more traditional metal-based or wooden constructions. For example, carbon fiber, a unique material, is used in a wealth of applications all over the world to reinforce composite materials, particularly the class of materials known as carbon fiber reinforced plastics. This class of materials is used in high-performance vehicles, wind generator blades and gears, aircraft parts, sporting
30 equipment, and other mechanical applications. Carbon fibers are usually mixed with a resin (cured to the B-stage) to form a "pre-preg" (or pre-impregnated with a resin) or a sheet impregnated with a resin, wound between release paper (or release paper impregnated with a resin on one side that is rolled on to the carbon fiber). For example, in high-performance

applications of composite materials (e.g., airline industry), fibrous materials impregnated with a resin ("prepregs") are the most used intermediate materials. As most carbon fiber and other fiber manufacturers are working in a state of constant development and improvement, there are a variety of fibers available for industrial applications including concrete. However, fibers that exhibit the desired properties as described in the description of the invention herein have not been previously reported. Moreover, there is a need for fibers that exhibit greater rigidity and water proofing or moisture resistant properties for use in concrete and other industrial and consumer products.

Concrete is used for a wide variety of purposes, including road and bridge building, and, in particular, for the supports of elevated road beds and highways, as well as pilings and pillars. Concrete also has uses in building structures such as skyscrapers, high rises, including commercial as well as residential applications. Concrete may be prepared as a mixture to which water may be added. This permits concrete to be poured and formed on site.

Alternately, concrete may be preformed and supplied in structures which may be moved into position, or, if heavy, lifted by a crane.

In addition, concrete, by its nature, has been known to undergo degradation, deterioration, crumbling, cracking, as well as separation of the concrete matrix. This can occur over time or by exposure to extreme or repeated weather or other environmental conditions. Stresses, such as wear, movement, vibrations and the like may also contribute to the aforementioned problems associated with concrete. It has been known in the art to install carbon and other fibers as components in a concrete product in the form of a filament or tow (i.e., a continuous yarn) or of specific dimensions to reinforce the hardened structural material. These filaments and fibers, however, still do not solve the problem as they are tight and unable to be penetrated. Thus, there is no way to bond a carbon filament yarn properly without some separation from the concrete structure. Other prior attempts to reinforce concrete include, in addition to carbon fibers, fiberglass, polymers and steel. See, U.S. Patent Nos.: 6,962,201; 6,263,629; 5,685,902; 5,422,174; and 5,366,600 and EP 288070. Further, due to hydrophilic nature of carbon and other fibers and corrosion considerations, carbon has seen limited success in concrete or metal matrix composite applications. Thus, there is also a

need for minimizing hydrophilicity of fibers and the corrosion of steel and other corrodable materials used as components of concrete mix.

Furthermore, it has become desirable in recent years to take protective measures in buildings, especially government buildings, against terrorist bombings. While structures, such as terrorist concrete barriers, have been used to help fortify buildings against bomb blasts, the force of a bomb blast often causes a portion of the terrorist concrete barrier to shatter, the shattered concrete debris created thereby projecting forcefully outwardly injuring or killing people it strikes and causing further damage to property near the bomb blast site. Therefore, a need exists for a way to reinforce the concrete to alleviate or minimize known problems and improve the life and function of the concrete.

Likewise, gypsum, which has many uses in the building trade, such as in wall boards, flooring, and roofing, has drawbacks of poor weather or environmental resistance, poor strength, poor flexibility, and poor toughness. A need exists for a way to reinforce gypsum products to improve their strength, flexibility, toughness and weather or environmental resistance.

SUMMARY OF THE INVENTION

In the present invention, it has been discovered that when fibers are texturized and coated with suitable resin(s), such fibers exhibit significant rigidity and water proofing or moisture resistant properties as compared to the non-texturized fibers. In addition, such fibers are also able to form stronger bonds with surrounding material(s) when used in a composite or mixture form with other materials.

Accordingly, in one aspect of the invention, an engineered fiber (a texturized fiber coated with a resin) is provided. The engineered fibers can be carbon fibers, glass fibers, nylon fibers, kevlar fibers and polyvinyl alcohol (PVA) fibers. The resin can be a thermoplastic resin or a thermosetting resin or a combination thereof. The resin is present in the amount of between about 2% and about 30% solids per dry weight of a given fiber. The engineered fiber has an average density that is less than the density of high tensile steel fiber of equal mass yet has characteristic high strength-to-weight and stiffness-to-weight ratios and can achieve the strength and stiffness of metals. The engineered fiber also has an ability to

form stronger interface bonds with other component in a mix as compared to control fibers that are non-texturized. A kit having a texturized fiber coated with a resin is also provided.

In another aspect of the invention, the present invention provides a method of preparing a reinforcement fiber involving texturing a fiber, providing molten thermoplastic resin containing composition, contacting the fiber with the composition and drying the fiber after contacting the fiber with resin composition to obtain the reinforcement fiber is provided. The molten thermoplastic composition has a viscosity ranging from about 1 cps to about 100 cps. The resin is present in an amount of between about 10% and about 20% solids, preferably 15-16% per dry weight of the fiber.

A method of preparing an engineered a fiber in a fabric form is also provided. It involves texturizing the fiber that is in the form of yarn, aligning individual yarn side by side on a roller to form a tape of a given width and having a first surface and a second surface, treating the aligned yarns with a water dispersible thermosetting resin and then curing the resin treated yarn thereby forming the fiber in a fabric form. The thermosetting resin has a viscosity ranging from about 100 cps to about 1000 cps at the time of treatment and the resin is present in an amount of between about 2 and 30% solids per dry weight of the fiber. The curing of the resin is accomplished by heating the fiber at about 50°C or to about 150°C.

In another aspect of the invention, concrete and other industrial and consumer products containing the engineered fibers that exhibit greater rigidity and water proofing or moisture resistant properties are disclosed.

In a preferred embodiment of the invention, the present invention comprises concrete having about 2½ inch long to about 6 inch long (more preferably about 2 inch long to about 3½ inch long, and even more preferably about 3 inch long) acrylic coated carbon fibers evenly dispersed throughout the concrete matrix. In accordance with the invention, the inclusion of the acrylic coated carbon fibers having lengths of about 2 inches long to about 6 inches long in the concrete improves the performance characteristics of the resulting concrete product with respect to degradation, deterioration, crumbling, cracking and separation, and the inclusion of such carbon fibers to the concrete increases the post-cracking resistance of the resulting concrete product that helps prevent deteriorated concrete from separating. The resulting concrete product has very high abrasion resistance.

In another preferred embodiment of the invention, the invention comprises concrete having about 2½ inch long to about 6 inch long (more preferably about 2½ inch long to about 3½ inch long, and even more preferably about 3 inch long) acrylic coated carbon fibers evenly dispersed throughout the concrete matrix of the concrete, and small (e.g., nano sized) silica fumes evenly dispersed throughout the concrete matrix of the concrete

In accordance with the invention, a preferred method of reinforcing concrete products comprises mixing (a) cement, (b) acrylic coated carbon fibers having a length of about 2½ inches to about 6 inches (more preferably about 2½ inches to about 3½ inches, and even more preferably about 3 inches) (c) water, and optionally (d) silica fumes and/or slag and/or stone and/or sand and/or other aggregates together to form a slurry wherein the carbon fibers are dispersed evenly throughout the slurry, and letting the slurry set in a form to cure the cement and form bonds between the cement and the carbon fibers, thereby obtaining reinforced concrete.

The inclusion of carbon fibers, in accordance with the invention, improves the strength, flexibility, toughness and weather or environmental properties of the concrete products. Concrete products of the present invention have improved flexural and deflection properties, improved impact strength and ductility, and improved permeability and compression properties. As used herein, the reference to concrete products includes cement products, as well as other products comprising cement and aggregate.

The concrete products produced in accordance with the present invention may preferably include barriers, in particular, jersey barriers, and terrorist barriers, including panels. In addition, the concrete products produced in accordance with the invention may comprise bridge decks, pre-cast concrete structures, pavements, slabs-on-grade, pipes, wall and floor panels, post-tensioned beam anchorage zones, as well as other uses where traditional concrete products have been used. The concrete products of the invention also have use in seismic applications.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view in perspective of a concrete product constructed in accordance with the invention.

Fig. 2 is a view in perspective of a concrete product constructed in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides a class of engineered fibers with desired mechanical and chemical properties than the prior art fibers useful for various applications including structural applications. The invention also relates to a process for manufacturing the engineered fibers and the fiber containing products prepared therefrom. The class of engineered fibers of the present invention is those fibers that have been texturized, unless stated explicitly that the fibers are non-texturized fibers. Such texturized fibers are then coated with suitable resin (s) that are water dispersible to form reinforcement fibers.

It is known in the art that fibers are made of a number of filaments. These filaments are stranded into a yarn. Indeed, yarn is rated in the industry by number of filaments per yarn count (usually in thousands) or by the linear density (weight per unit length = $1 \text{ g}/1000 \text{ m} = \text{tex}$). Carbon fibers can be obtained in various yarn sizes including 320K, 120K 40K and 24K (lower cost carbon fibers) 12K, 6K, 3K and 1K (high cost carbon fibers). This yarn can then be used to make or weave a carbon fiber fabric or cloth.

One skilled in the art would also appreciate that there are different grades of fibers characterized by their modulus, tensile strength, density and other properties. For example, carbon fibers are available in standard modulus (240 GPa) , intermediate modulus (300 GPa) and high modulus ($> 300 \text{ GPa}$). The tensile strength of different yarn types varies between 2000 and 7000 MPa. The average density of carbon fiber is typically in the order of $1750 \text{ kg}/\text{m}^3$. The average density of fiber equals its total mass divided by its total volume. PVA fibers having tensile strengths 1100 MPa (160,000 psi) to 1400 MPa (203,000 psi) are commercially available

Various fibers contemplated in the present invention include carbon fibers, glass fibers (e.g., "E-type" glass fibers or alkaline resistant glass fibers), nylon fibers, polyvinyl alcohol (PVA) fibers, and such others characterized by low weight compared to steel and other metals, and having good tensile strength, tensile modulus, density and specific strength. For example, glass fibers having about 3.5 tensile strength (GPa), 22.0 tensile modulus (GPa), 2.60 density (g/ccm) and 1.3 specific strength (GPa) are known. Other fibers having similar properties can be used to make reinforcement fibers The term "fiber" as used herein does not include steel fiber or cellulosic fiber, but includes those fibers that have high tensile strengths

ranging from 1.1-3.6 GPa. Fibers having tensile strengths of, for example, 3.6 GPa (Kevlar), 3.5 GPa (carbon), 3.4 GPa (E Glass) and 1.4 GPa (PVA) are commercially available.

The fibers are texturized by subjecting them to a suitable treatment to open the compressed or closely spaced filaments in the fibers (which treatment is sometimes referred to herein as a treatment to open up the fibers). The fibers can be opened, for example, by exposing the fibers to a pressurized stream of air, preferably hot air, or by unwinding the yarn or thread to uncompress or loosen up the compressed filaments in the fiber, knit and de-knit process, combing or by teasing the fibers by mechanical or other suitable means. As a result, the texturized portion of a fiber should always have a greater diameter or width than the dimensions of the non-texturized portion of the fiber. Texturized fibers may be produced by mechanical, physical and/or chemical means but it should not involve aqueous chemical treatments (e.g., soaking in water or sodium hydroxide solution).

Such texturized fibers are exposed to a suitable resin or a mixture of resins (e.g., epoxy or acrylic resins). In the present invention, the term "resin" is used to refer to the monomer or oligomer as well, which are not yet polymerized or cured. One skilled in the art knows that the resin and a composition having the elements (e.g., curing agent(s) including light or UV light) which are required for the polymerization or curing reaction are mixed to obtain a cured resin or cured product. The resin composition after the polymerization or curing reaction is carried out is called cured resin or cured product (e.g., cured product of an epoxy resin composition). For example, any of a number of art known thermoplastic and/or thermosetting resins can be used. These resins include polyester resin, vinyl ester resin, polyolefin, polystyrene, poly(vinyl chloride), polyester, polyamide or polypropylene, hydroxypropyl cellulose, ethyl cellulose, ethyl hydroxyethyl cellulose, N-substituted acrylamides, poly(vinylmethylether), poly(ethylene oxide), poly(vinylalcohol) and poly(2-ethyl oxazoline), methyl cellulose ether, cellulose acetate, cellulose acetate phthalate and cellulose acetate butyrate.

The resin can be either a thermoplastic resin or a thermosetting resin or a combination of the two types. Resin treatments generally known in the art can be used. The resin coated onto the fiber is allowed to be in either a fully cured state (if the resin used is a thermoplastic resin) or a semi-cured state (if the resin is a thermosetting resin).

It should be noted that the semi-cured fibers of the present invention do not include the prior art known semi-cured fibers that are cured only to the B-stage such as, for example, those disclosed in the U.S. Patents 6,263,629 and 5,836,715). The fibers of the present invention are those that are cured to a stage beyond the B-stage, where the resin appears to be in a fully cured state, (e.g., is a flexible solid) but actually is not completely cured, and to the C-stage. In this regard, prior art prepregs (from airline industry, for example) wherein the resin that is impregnated in the fiber is cured only to the B-stage can be modified by suitable agents (e.g., catalysts) that would significantly increase the viscosity of the resin. The C-stage resin, for purposes of the present invention, is not a fully cured form. The resin cured to the C-stage according to the present invention is rigid enough to hold its shape (does not curl up), dry and has no tack. The C-stage fibers of the present invention are more hydrophobic than the prior art known fibers coated with resins cured to the B-stage.

The texturized and resin treated fibers of the present invention (reinforcement fibers) can have characteristic high strength-to-weight and stiffness-to-weight ratios and can achieve the strength and stiffness of metals at significant weight savings. As a result, these fibers can be used commonly as high performance reinforcement structural materials such as concrete, automotive, aircraft, marine, audio, athletic, non-crimp fabrics and for aesthetic materials.

Without wishing to be bound by any particular theory, it is believed that texturization increases the overall surface area of the fibers by opening up the fibers. When such fibers are coated with a resin or a mixture of resins, the relative surface area coated or saturated with the resin is increased. Because the adhesive or bonding strength is a function of surface area, the textured fiber exhibits a relatively high bonding strength as compared to the control fibers. Also, the reinforcement fibers show relatively non-glossy surface.

The reinforcement fibers of the present invention exhibit greater rigidity and water proofing or moisture resistant properties as compared to the non-texturized fibers (control fibers). For example, the reinforcement fibers can reduce the amount of water penetration in concrete and premature deterioration of the concrete in a freeze-thaw environment as compared to the control fibers. With regard to water resistance, a non-wettable surface is termed in the prior art as hydrophobic and a wettable surface hydrophilic. The reinforcement fibers of the invention exhibit greater hydrophobic properties as compared to the corresponding control fibers. One skilled in the art knows how to determine hydrophobicity

of a given material. Hydrophobicity can be determined, for example, by a contact angle measurement, which is a measurement to determine wettability. For example, a contact angle of 90° or greater generally characterizes a surface as non-wettable, and one less than 90° means that the surface is wettable. Some surfaces have contact angles greater than 150° (superhydrophobic), showing almost no contact between the liquid drop and the surface.

In addition, as mentioned above, the reinforcement fibers of the present invention are well-suited for a wide variety of applications because of their superior molecular bond strength as compared to the control fibers. Specifically, the fibers form stronger chemical and/or physical bonds (interface bond) with surrounding material(s) when used in a composite or mixture form with other materials (e.g., cement mix or mortar) and thus are superior structural fibers as compared to the control fibers. One skilled in the art would know how to compare interface bonding ability of the reinforcement fibers with that of the control fibers when in a mix such as cement mix or mortar. A qualitative assessment would be, for example, to compare cement slurry containing a given reinforcement fiber to a slurry containing only the control fibers by means of a microscopy technique (e.g., scanning electron microscopy).

In the present invention, the reinforcement fibers are by obtained by treating the fibers with a suitable resin composition before they are used are for various applications such as for making concrete or laminates etc. Depending on the type of application and cost considerations, only one kind of fibers (homogeneous) or a mixture of different fibers (heterogeneous) can be used. For example, carbon fibers can be mixed with glass fibers, which are usually less expensive than carbon fibers and still realize high strength-to-weight and stiffness-to-weight ratios, and achieve the strength and stiffness of metals at significant weight savings when used as high performance reinforcement structural materials. Similarly, carbon and PVA fibers can be used together as a highly effective hybrid for fiber-reinforced cement composites. In addition to cement composites, it is also contemplated in the present invention, that these fibers can be used as composites such as a mixture of different kinds of fibers (hybrid fibers) in one or more layers or as multiple individual layers (e.g., a carbon fiber layer and a layer of glass fibers, either laminated together or without lamination) of woven and/or non-woven fiber materials, fabrics etc. The fibers can be mixed with silica fumes for certain applications such as concrete products.

The layers can be made of unidirectional fibers or other forms of fiber arrangements. Layers may be used individually or as a hybrid. As will be readily appreciated by those of ordinary skill in the art, these hybrid constructions provide a plurality of staggered yarn floats, where a yarn extending in one direction crosses over two or more yarns extending in the other
5 direction. The choice of resin(s) in the reinforcement fibers, layering sequence, layer type can be specified according to the desired mechanical properties and cost considerations.

Also disclosed herein are certain processing steps to obtain the improved fibers of the present invention. Essentially, to obtain reinforcement fibers, the process involves steps of texturizing a fiber to open up the fiber and contacting the fiber with suitable resin(s) to
10 produce the reinforcement fiber. The reinforcement fiber so obtained should exhibit greater rigidity and hydrophobic properties compared to the non-texturized fiber. If the non-coated fiber itself is hydrophobic, the thermoplastic and/or thermosetting polymer lends added hydrophobicity.

Resin treatments generally known in the art can be used in combination with the texturization step of the invention. For example, treatment of materials with heat-curing,
15 autopolymerizing (self-cure or cold-cure), thermoplastic, and light-curing resins such as acrylic resins are known in the art. Acrylic coating is routinely used in the textile industry.

In one embodiment of the invention, fibers are processed using a standard textile coating or dye bath process to produce acrylic resin coated reinforcement fibers. As part of
20 the texturizing step, the fibers (e.g., in yarn form) can be advance through the gap between pair(s) of opposing rollers forming a converging nip between them. The construction of the rollers is conventional and those skilled in the art would know how to assemble such rollers to provide for the necessary compression forces. The effect is to open up the fibers. The next step in the process is to contact the texturized fibers with a resin or a mixture of resins. It can
25 be performed by immersing the fibers in a bath of resin(s), for example acrylic resin bath. The individual yarn (or tow) that has been texturized can be contacted with resin(s). Preferably, the coating of the texturized fiber is done "inline" immediately before any further processing of the fiber. The resin bath is prepared according to the manufacturer's instructions by adding appropriate hardners and/or catalyst so as to facilitate curing of resins
30 after the contacting step. An alternative coating method may employ a thermoplastic composition wherein it is thermally made flowable and released from a coating device onto

the texturized fiber. This sort of coating process (using a resin bath or a coating device) is preferred for coating fibers with thermoplastic resins. Acrylic resin based thermoplastic composition is preferably coated at temperatures of less than about 170°F, more preferably between 120°F and 160°F using standard coating procedures and the textile process. It will be appreciated by one skilled in the art that if the fiber used is a thermally sensitive fiber then the coating temperature should be less to reduce the heat-induced stresses on the fiber being coated. In a preferred embodiment, the resin is an acrylic resin and is present in amount of about 16% per dry weight of the fiber.

In another embodiment, a tape of semi-cured fibers is produced. Preferably, the resin used in this process is a thermosetting resin. To create the tape, the individual yarn (tow) (e.g., a standard modulus carbon yarn 45K that is ½ inch wide) is put on spools and pulled into a suitable machine to open up the yarn (fiber) by combing process, and aligned on rollers side by side. The amount of spools of yarn determines the width of the tape. A suitable resin is formulated and coated onto a release paper that is rolled on top of one side of the fibers, pulled through the machine, and heated to liquefy the resin so that it permeates or impregnates the fibers. The percentage of resin coating and the amount of heat and duration of the heating is determined by the type of resin and the end use. The coated tape may then be re-rolled with the release paper and cooled.

Normally, the coated surface of a thermosetting resin impregnated fiber is tacky. This is referred to in the prior art as a B-stage. The finished B-stage material must be kept refrigerated to keep its state. This stage would be suitable in those situations that require adherence to another layer of material. In the present invention, however, fiber material having a non tacky surface (or zero tack surface of the coated fiber or less tacky surface than the B-stage material) is used. To accomplish this, the resin is reformulated by adding a flow modifier or a hardener and the resin coated fiber is processed to cure the resin. In the resulting coated material (C-stage material), there should be zero surface tack or no surface tack. This C-stage material can be kept at ambient temperature (e.g., room temperature) with no change to its state. One skilled in the art would know how to choose a suitable flow modifier and mixing ratios based on the desired temperature conditions, curing thickness, desired working time and desired drying times.

For example, a low temperature resin that can fully cure at 150 degrees in about 1½ to 2 hours may be used as a starting resin material. This resin is formulated by mix it with a flow modifier such as, for example, isoprene diamine (1 to 1½% by weight). This accelerates the curing and promotes drying to create zero surface tack. The fiber material after contacting
5 with such a resin composition is preferably processed at a consistent heat and line speed at a temperature between 180°F and 230°F degrees from 2 to 10 minutes. This should allow the resin to liquefy and impregnate the fibers. The resin coated material is then cooled to room temperature. The resulting material is a C-stage material as defined herein. In this manner a tape of reinforcement fiber desired width and length (e.g., 20 to 30" wide rolls) can be
10 produced. It should be noted that, in some embodiments of the present invention, non-texturized fibers can be coated with a thermosetting resin and processed to obtain the C-stage material.

The fibers can then be formed into various configurations. The fibers can be sliced, milled and/or chopped into pieces of desired sizes or lengths depending on the type of
15 application, as would be appreciated by one of ordinary skill in the art. For example, the approximate and/or average lengths may range from ⅛" to 6" or more depending on the application. For example the fibers can be anywhere from 1" to 6" long, in the increments of 0.5" such as 1.5", 2", 2.5", 3", 3.5", 4", 4.5" and so on. Likewise the approximate and/or average width of the chopped fibers may range from ¼" to ½", about 1" or about 2" or more
20 as needed. For example, the width can be anywhere from ¼" to 2" in the increments of ¼".

The reinforcement fibers of the present invention can be used in a number of ways as will be recognized by those skilled in the art. One preferred use is in concrete, grout or wallboard mixtures for purposes of improving the performance characteristics of the resulting products with respect to, for example, their degradation, deterioration, crumbling, cracking
25 and separation as will be clear from the following description of preferred embodiments.

I. A concrete product in accordance with the invention comprises concrete and carbon fibers.

The carbon fibers are in the form of (a) carbon graphite fibers having a length of about 2 ½ inches to about 3 ½ inches, preferably about 3 inches, and/or (b) micron and/or nano
30 sized carbon graphite fibers. The carbon graphite fibers may be based, for example, upon pan

carbon, pitch carbon, rayon and cotton carbon. Preferably, the carbon fibers have approximately 500,000-pound tensile strength and approximately 32-million-modulus.

Preferably, the concrete is made from cement, such as Portland cement, or a mix comprising cement, such as Portland cement, and slag and/or stone and/or sand and/or other
5 aggregates. Alternately, the concrete may comprise Portland cement concrete without the further addition of aggregate.

The invention also includes a concrete mix comprising (a) cement, preferably Portland cement (b) carbon graphite fibers having a length of about 2 ½ inches to about 3 ½ inches, preferably about 3 inches, and/or micron and/or nano sized carbon graphite fibers, and
10 optionally (c) slag and/or stone and/or sand and/or other aggregates.

Concrete may be varied in composition so as to provide the desired characteristic properties required for a particular application. For example, a concrete slurry in accordance with the invention may contain 10 to 18 % cement, 60 to 80 % aggregate, 15 to 20 % water, and 0.5 to 2 % carbon fibers. Entrained air in the slurry may take up to about 8 %.
15 Additionally, in accordance with the invention, cement slurries having different percentages of components than those percentages of the example of this paragraph are included in this invention.

In a preferred embodiment of the invention, a concrete product is produced from a mixture comprising from about 97.5 % - 99% by weight of cement, and from about 1% to about 2% fibers. Alternately, slag may be added to the mixture, with the slag component
20 being present in an amount of up to about 40% by weight of the mixture (or up to about 40% by weight of the mixture, the concrete and slag being inclusive), the fiber content preferably in an amount of from about 1% to about 2% by weight of the mixture, and the cement being present in an amount of from about 74% to 98%. In a particularly preferred embodiment, the
25 slag is present in an amount of about 25% by weight, the cement is present in an amount of about 74% by weight, and 2 ½ in. to 3 ½ in. carbon fibers are present in an amount of about 1.5% by weight.

In a preferred embodiment, the carbon fibers having a length between about 2 ½ inches to about 3½ inches are evenly dispersed throughout the concrete matrix. Carbon
30 graphite fibers having the length of about 2 ½ inches to about 3 ½ inches that are evenly dispersed in the concrete matrix facilitate the prevention of cracking and separation of the

concrete matrix. When the carbon graphite fibers having a length of about 2½ inches to about 3½ inches are present in a concentration of about 1% to about 2% by weight of the concrete product, separating, cracking, and deteriorating of the concrete may be decreased by 250% to 500% compared with the prior art. Under tensile stresses, the fibers bridge the cracks and restrain the widening of the concrete by providing pullout resistance. The fibers lead to the improvement of the post peak ductility and toughness of the material. The formation of cracked systems in the cement is minimized or prevented, thus increasing the tensile strength on the overall toughness of the inventive composite material. The carbon fibers do not rust, have super tensile strength, and are inert to chemicals.

In preferred embodiments of the invention where the carbon fibers comprise carbon fibers having the length of about 2½ inches to about 3½ inches, the 2½ in. to 3½ in. fibers are provided in a range of about 1% to about 2% by weight of the concrete mix or concrete product, with 1.5% by weight of the concrete mix or concrete product being more preferred.

In another preferred embodiment, the invention comprises cement (preferably Portland cement), nano and/or micron sized carbon graphite fibers, and optionally slag and/or stone and/or sand and/or other aggregates. The density of the finished concrete matrix of a concrete product produced with the composition of the present invention may be increased through the addition of the nano or micron sized carbon particles, or mixtures of nano and micron sized particles.

The concrete products of the invention containing the micron and/or nano sized carbon graphite fibers have improved properties. For example, the inventive concrete products exhibit an increase in the flexibility of the concrete as well as an increase in the deflection of the concrete. When the carbon fibers are present at a concentration of about 0.5% to 2% by weight of the concrete product, the concrete flexibility is increased by about 300 % and the concrete deflection is increased by about 500 %. As little as about 0.5% concentration of the carbon graphite fibers in the concrete mix imparts beneficial improvements in strength to the resultant concrete products, and aids in minimizing some or all of the deficiencies (such as degradation, crumbling, cracking, and separating of the concrete matrix) observed with traditional concrete products. Abrasion and erosion are diminished with the interlocking of

microscopic carbon graphite fibers. The fibers also extend the concrete fatigue lifetime. In preferred embodiments of the invention where the carbon fibers comprise nano sized fibers, the nano sized carbon fibers are provided in a range of about 0.5% to about 1% by weight of the concrete mix or concrete product, with 0.75% by weight of the concrete mix or concrete product being more preferred. In preferred embodiments of the invention where the carbon fibers comprise micron sized fibers, the micron sized carbon fibers are provided in a range of about 0.5% to about 1% by weight of the concrete mix or concrete product, with 0.75% by weight of the concrete mix or concrete product being more preferred. In preferred embodiments of the invention where the carbon fibers comprise a combination of nano sized fibers and micron sized fibers, the combination of nano sized carbon fibers and micron sized fibers is provided in a range of about 0.5% to about 1% by weight of the concrete mix or concrete product, with 0.75% by weight of the concrete mix or concrete product being more preferred.

In another preferred embodiment of the invention, the carbon fibers include 2½ in. to 3½ in. fiber lengths, and nano sized lengths or nano-fumes, which is about one billionth of a meter (10^{-9} m) or about 0.0000000001 meters (0.1 nm) to 400 microns or to 200 microns. In some embodiments, nano sized lengths are at least 1 nanometer but less than 1000 nanometers (e.g., 10, 50, 100, 200, and/or 500 nanometers) and micron sized lengths are at least 1 micrometer and can be up to about 400 microns (e.g., 10, 50, 100, 200, and/or 400 micrometers). For example, the concrete product can contain concrete plus the addition of about less than 10% nano fibers. The concrete products of the invention to which nano fibers have been added should have significantly improved properties. For example, the concrete products preferably increase the flexibility of the concrete as well as an increase in the deflection of the concrete. For example, when the nano-sized carbon fibers are present at a concentration of about 0.25% to 2% by weight of nano fiber content to concrete content, the concrete flexibility is unexpectedly increased by about 300% and the concrete deflection is increased by about 500%. As little as 0.25% concentration of the carbon graphite fibers in the concrete mix imparts beneficial improvements in strength to the resultant concrete products, and aids in minimizing some or all of the deficiencies observed with traditional concrete products.

In further embodiments, the carbon fibers include (a) the 2½ in. to 3½ in. fiber lengths, and (b) micron sized carbon fibers or a combination of micron sized and nano sized fibers.

The inclusion of the micron and/or nano sized particles may be done to improve permeability (thereby hindering water degradation) and compression of the finished concrete

5 product. In preferred embodiments of the invention where the carbon fibers comprise a combination of 2½ in. to 3½ in. fibers and nano sized fibers, the 2½ in. to 3½ in. fibers are provided in a range of about 1% to about 2% by weight of the concrete mix or concrete product, with 1.5% by weight of the concrete mix or concrete product being more preferred, and the nano sized fibers are provided in a range of about 0.5% to about 1% by weight of
10 the concrete mix or concrete product, with 0.75% by weight of the concrete mix or concrete product being more preferred. In preferred embodiments of the invention where the carbon fibers comprise a combination of 2 ½ in. to 3 ½ in. fibers and micron sized fibers, the 2 ½ in. to 3 ½ in. fibers are provided in a range of about 1% to about 2% by weight of the concrete mix or concrete product, with 1.5% by weight of the concrete mix or concrete product being
15 more preferred, and the micron sized fibers are provided in a range of about 0.5% to about 1% by weight of the concrete mix or concrete product, with 0.75% by weight of the concrete mix or concrete product being more preferred. In preferred embodiments of the invention where the carbon fibers comprise a combination of 2 ½ in. to 3½ in. fibers and nano sized fibers and micron sized fibers, the 2 ½ in. to 3 ½ in. fibers are provided in a range of about 1% to about
20 2% by weight of the concrete mix or concrete product, with 1.5% by weight of the concrete mix or concrete product being more preferred, and the combination of nano sized fibers and micron sized fibers is provided in a range of about 0.5% to about 1% by weight of the concrete mix or concrete product, with 0.75% by weight of the concrete mix or concrete product being more preferred.

25 In each embodiment of the invention that includes carbon graphite fibers having a length of about 2½ inches to about 3½ inches as a component, the carbon graphite fibers having a length of about 2½ inches to about 3½ inches preferable are texturized prior to being mixed with the cement to open up the fiber filaments to allow the cement to penetrate into the interstices of the fibers to permit the creation of a permanent bond between the cement and
30 the fibers.

Also, in each embodiment of the invention that includes carbon graphite fibers having a length of about 2½ inches to about 3½ inches as a component, a dispersing agent is preferably used to facilitate even dispersion of the carbon graphite fibers having a length of about 2½ inches to about 3½ inches throughout the concrete mix and/or the concrete slurry.

5 A preferred dispersing agent is a light epoxy compound which may be coated on the carbon fibers having a length of about 2½ inches to about 3½ inches. Preferably, the epoxy compound is coated on the carbon fibers having a length of about 2½ inches to about 3 ½ inches in an amount of about 0.3% to about 0.9% by weight of the carbon fibers, or in a sufficient amount to provide an adequate coating on the carbon fibers.

10 The following some of the examples that are illustrative of the invention.

EXAMPLE 1

Component	Weight	Percent by Weight
Cement	800 lbs	98.5 %
2 ½ in. to 3 ½ in. long fibers	12 lbs	1.5 %
Total	812 lbs	100%

The components are mixed together, and water is added to the dry mixture of components. The fibers comprise chopped carbon graphite fibers. Prior to mixing the carbon
 15 fibers with the cement, the carbon fibers are texturized by subjecting them to a pressurized stream of hot air to open the filaments in the fibers to allow the cement to penetrate into the interstices of the fiber and create a permanent bond between the cement and the fiber. Also, prior to mixing the carbon fibers with the cement, the carbon fibers after being subjected to the pressurized stream of hot air are coated with a light epoxy compound to provide rigidity to
 20 the fibers which facilitates the even dispersion of the fibers throughout the cement during mixing. A commercial blender, such as a rotary action mixer, may be used for the mixing.

The following Examples 2 to 18 further illustrate the invention. In each example, the procedures set out in Example 1 are used, except if the components do not include carbon graphite fibers having a length of about 2 ½ inches to about 3 ½ inches, the texturizing step
 25 and epoxy coating step are skipped.

EXAMPLE 2

Component	Weight	Percent by Weight
Cement	782 lbs	97.75 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	12 lbs	1.5 %
Micron sized carbon graphite fibers	6 lbs	0.75 %
Total	800 lbs	100%

EXAMPLE 3

Component	Weight	Percent by Weight
Cement	782 lbs	97.75 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	12 lbs	1.5 %
Micron sized carbon graphite fibers	6 lbs	0.75 %
Total	800 lbs	100%

EXAMPLE 4

Component	Weight	Percent by Weight
Cement	782 lbs	97.75 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	12 lbs	1.5 %
Micron sized carbon graphite fibers	3.2 lbs	0.4 %
Nano sized carbon graphite fibers	2.8 lbs	0.35 %
Total	800 lbs	100%

5

EXAMPLE 5

Component	Weight	Percent by Weight
Cement	600 lbs	73.9 %
Slag	200 lbs	24.6 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	12 lbs	1.5 %
Total	812 lbs	100%

EXAMPLE 6

Component	Weight	Percent by Weight
Cement	600 lbs	75 %
Slag	182 lbs	22.75 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	12 lbs	1.5 %
Nano sized carbon graphite fibers	6 lbs	0.75%
Total	800 lbs	100%

EXAMPLE 7

Component	Weight	Percent by Weight
Cement	600 lbs	75 %
Slag	182 lbs	22.75 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	12 lbs	1.5 %
Micron sized carbon graphite fibers	6 lbs	0.75%
Total	800 lbs	100%

5

EXAMPLE 8

Component	Weight	Percent by Weight
Cement	600 lbs	75 %
Slag	182 lbs	22.75 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	12 lbs	1.5 %
Nano sized carbon graphite fibers	6 lbs	0.75%
Micron sized carbon graphite fibers	3.2 lbs	
	2.8 lbs	
Total	800 lbs	100%

EXAMPLE 9

Component	Weight	Percent by Weight
Cement	800 lbs	99.25 %
Nano sized carbon graphite fibers	6 lbs	0.75 %
Total	806 lbs	100%

EXAMPLE 10

Component	Weight	Percent by Weight
Cement	800 lbs	99.25 %
Micron sized carbon graphite fibers	6 lbs	0.75 %
Total	806 lbs	100%

5

EXAMPLE 11

Component	Weight	Percent by Weight
Cement	600 lbs	73.9 %
Slag	205 lbs	25.2 %
Nano sized carbon graphite fibers	7 bs	0.86 %
Total	812 lbs	100 %

EXAMPLE 12

Component	Weight	Percent by Weight
Cement	600 lbs	73.9 %
Slag	205 lbs	25.2 %
Micron sized carbon graphite fibers	7 bs	0.86 %
Total	812 lbs	100%

EXAMPLE 13

Component	Weight	Percent by Weight
Cement	600 lbs	17 %
Slag	200 lbs	5 %
Nano sized carbon graphite fibers	56 bs	1 %
Stone	1,864 lbs	49 %
Sand	1,108 lbs	29 %
Total	3,828 lbs	100 %

EXAMPLE 14

Component	Weight	Percent by Weight
Cement	600 lbs	16 %
Slag	200 lbs	5 %
Micron sized carbon graphite fibers	56 lbs	1 %
Stone	1,864 lbs	49 %
Sand	1, 108 lbs	29 %
Total	3,828 lbs	100 %

EXAMPLE 15

Component	Weight	Percent by Weight
Cement	600 lbs	15.7 %
Slag	171.5 %	4.5 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	67.5 lbs	1.8 %
Stone	1,864 lbs	48.9 %
Sand	1,108 lbs	29.1 %
Total	3,811 lbs	100 %

5

EXAMPLE 16

Component	Weight	Percent by Weight
Cement	600 lbs	15.7 %
Slag	171.5 %	4.5 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	39 lbs	1 %

Nano sized carbon graphite fibers	28.5 lbs	0.8
Stone	1,864 lbs	48.9 %
Sand	1,108 lbs	29.1 %
Total	3,811 lbs	100 %

EXAMPLE 17

Component	Weight	Percent by Weight
Cement	600 lbs	15.7 %
Slag	171.5 %	4.5 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	39 lbs	1 %
Nano sized carbon graphite fibers	28.5 lbs	0.8
Stone	1,864 lbs	48.9 %
Sand	1,108 lbs	29.1 %
Total	3,811 lbs	100 %

EXAMPLE 18

Component	Weight	Percent by Weight
Cement	600 lbs	15.7 %
Slag	171.5 %	4.5 %
2 ½ in. to 3 ½ in. long carbon graphite fibers	39 lbs	1 %
Micron sized carbon graphite fibers	14.24	0.4 %
Nano sized carbon graphite fibers	14.25 lbs	0.4 %
Stone	1,864 lbs	48.9 %
Sand	1,108 lbs	29.1 %
Total	3,811 lbs	100 %

5

II. Alternatively, in accordance with other embodiments of the invention, although not as effective, silica fumes or the combination of silica fumes and micron and/or nano sized carbon graphite fibers may be used in place of micron and/or nano sized carbon graphite

fibers in the same concentrations used in the embodiments of the invention which contain micron and/or nano sized carbon graphite fibers set out above, and which also contain the 2 ½ in. to 3 ½ in. carbon fibers.

In accordance with the method of the invention, the components are mixed together, and to the dry mixture of components is added water (about 20% by weight) to form a concrete composition ready to be used that has greater strength, flexibility, toughness, and weather or environmental resistance properties than concrete not having the carbon graphite fibers of the invention. The carbon fibers having a length of about 2 ½ inches to about 3 ½ inches, when used as a component of concrete, prior to mixing are preferably “opened up” by subjecting such carbon fibers to a texturizing step, such as by subjecting such carbon fibers to a stream of hot pressurized air. In addition, the method of reinforcing and improving the performance characteristics of concrete preferably includes the step of providing a dispersing agent when carbon graphite fibers having a length of about 2 ½ inches to about 3 ½ inches are used as a component of the concrete. Preferably, the dispersing agent is a light epoxy compound, and is used to provide a coating on the carbon fibers having a length of about 2 ½ inches to about 3 ½ inches prior to the introduction of such carbon fibers into the cement mix. The carbon fibers are mixed with the cement and any additional components, such as, for example, the slag (e.g., see Examples 11-18), and a suitable amount of water is added to arrive at the consistency for a concrete slurry. Preferably, when 2 ½ inches to about 3 ½ inches long fibers are used, mixing in a commercial blender is done without high pressure or a chopping action and is kept to a minimum to avoid damage to the fibers. When mixing in a mold or form, the fibers may be dispersed by direct spraying.

After the concrete slurry is created and is allowed to set in a form, the form is removed, and the result is a concrete product.

Turning to Fig. 1, there is shown a concrete product 11, in the form of a barrier, constructed in accordance with the invention. The concrete product 11 comprises a body 13 having a base 15, a front face 17, a rear face 19, side faces 21 and 23, and an upper end surface 25. Concrete products 11 are produced using the method set out above from (a) cement, preferably Portland cement, (b) carbon graphite fibers having a length of about 2 ½ inches to about 3 ½ inches (preferably about 3 inches), and/or micron and/or nano sized carbon graphite fibers, and optionally (c) slag and/or stone and/or sand and/or other

aggregates. In alternative embodiments of the invention, the concrete products 11 are produced using the method set out above from (a) cement, preferably Portland cement, (b) silica fumes or silica fumes with carbon graphite fibers having a length of about 2 ½ inches to about 3 ½ inches (preferably 3 inches) and/or micron and/or nano sized carbon graphite fibers, and optionally (c) slag and/or stone and/or sand and/or other aggregates. Examples of the compositions of the concrete products 11 are given in Examples 1 to 18. With respect to the concrete products 11 that include silica fumes, the silica fumes or the combination of silica fumes and micron and/or nano sized carbon fibers may be used in place of the micron and/or nano sized carbon fibers in the same concentrations used in the embodiments of the invention set out above. The mixes of the compositions and/or products thereof may also be referred to as cement mixes or cement products.

The concrete products of the invention have improved performance characteristics over prior art concrete products. For example, the concrete products of the invention have improved overall strength. The overall strength is improved to provide the finished matrix of the concrete product with high impact and resistance properties.

The concrete products 11 of the present invention include Jersey barriers and terrorist barriers, including panels. Among other products which may be produced in accordance with the present invention are included: precast (non-prestressed) panels, such as for example, tilt-up wall panels, floor panels, and the like), bridge decks, post-tensioned beam anchorage zones, pre-cast beams, pipes, slab-on-grade, seismic applications, as well as airstrip pavement.

The concrete products 11 of the present invention may also be constructed to have unproved hydration properties,. in particular, when the nano sized fibers are used. The nano sized carbon fibers contribute to a strong pozzolanic reaction, wherein the cement gains hydrate and generates calcium hydroxide, which in turn reacts to create more calcium silicate hydrate. The nano fibers also facilitate the reduction of bleeding and the amount of surface areas in the mix, leading to a stronger matrix.

In a further preferred embodiment of the invention, a concrete product in accordance with the invention comprises concrete and carbon graphite fibers as described below. The concrete product is reinforced through the following steps which are employed to produce a reinforced concrete product. The carbon fibers are closed by compressing the fibers, and are semi-cured with a curing agent, such as with a suitable resin, like an epoxy. The semi-cured

carbon fibers are mixed with a cement mix and preferably are mixed so as to be uniformly dispersed throughout the mix. The cement mixture with the semi-cured carbon fibers is then hydrated with the addition of water, and the mixture is permitted to cure or set to form a cement or concrete product.

5 The carbon fibers preferably are tightly compressed carbon graphite fibers having a resinous material, such as an epoxy coating, on them. The carbon fibers preferably may be supplied in a fabric or tape-like form wherein a thin sheet of a binder, such as an epoxy resin holds a plurality of carbon fibers together. Preferably, the carbon fibers are arranged in a unidirectional orientation. The resinous material, such as an epoxy resin binder, is preferably
10 maintained at suitable temperature conditions to prevent premature curing of the epoxy resin to a hardened, brittle state. Preferably, the resinous material is maintained at a temperature of from between about 32°F to less than about 180°F.

 Preferably, the coating material, such as an epoxy, used to coat the carbon fiber is an effective resinous material that provides resistance against the water absorption (e.g., provides
15 hydrophobic properties to the carbon fiber) and sufficient rigidity to allow the fiber to maintain its shape in the slurry mix.

 The carbon fibers preferably may have a width of about 1/8" to about 1", with a preferred width being between about 1/4" to 1/2". The carbon fibers preferably may have a length of about 1" to about 6" or about 1" to about 4", with a preferred length being from
20 about 2 1/2 inches to about 3 1/2 inches.

 The carbon fibers preferably are utilized in the concrete mixture in the form in which they are held by the resinous material and supplied in small pieces. For example, a tape of approximately 2" width, which has carbon fibers of approximately 3" in length may be cut into smaller pieces prior to mixing it with the other cement or concrete components.

25 The carbon fibers may comprise pan carbon held with a resinous substrate, such as, for example, an epoxy resin.

 Carbon fibers suitable for use in the invention include carbon fibers that have been pre-pregged. For example, one preferred type of carbon fiber is a carbon yarn material which is coated with an epoxy called a prepreg. The material is put through a series of rollers
30 compressing the resin into fibers. Preferably, the rollers used to perform the compressing are heated. The heat along with the compression changes the resin's viscosity into an almost

liquid state. The liquid state or semi-liquid state of the resin facilitates penetration of the carbon fibers. Once penetrated or coated, the material is cooled, and preferably placed into storage at a lower temperature, a cold temperature. The material may remain in cold storage until ready to use. The cold storage minimizes the likelihood of the material curing or
5 becoming embrittled. The material may be stored for a period of time, and generally has a shelf life of up to about 6 months. Generally, the stage at which the carbon prepreg material is used is a stage after the B-stage.

The epoxy resin, however, must not be fully cured, but rather, is provided in the form of a partially cured condition or stage. Preferably, the carbon fibers are bound with epoxy
10 resin, and the epoxy resin is partially cured. It is most preferred that the epoxy resin binding the carbon fibers is in a stage where the resin appears to be in a fully cured state, (e.g., is a flexible solid) but actually is not completely cured, and from that stage may be cured further. Preferably, the epoxy resin useful in the present invention may be cured beyond that stage, and to a point before full curing of the resin. The preferred carbon fibers are unidirectional
15 prepreg carbon fibers cured to the "C-stage".

The carbon fibers and resinous material, such as epoxy resin, in its partially cured condition, is preferably added to the concrete mix, the mix is hydrated with water to form a slurry which may be poured into a form, permitted to set, to form a reinforced concrete or cement product.

20 The carbon fibers may comprise waste material from aircraft production. For example, the carbon fibers may be provided in the form of "carbon waste", a product which is produced by aircraft companies. The "carbon waste" material is generally formed from a carbon warped beam fabric coated with a resin, such as an epoxy or other resins, but which is only partially cured. The aircraft companies routinely use the carbon fabric by cutting it into
25 forms and laminating it to the aluminum wings or other parts of an aircraft. However, there is often waste produced when the carbon warped beam fabric is cut into forms: The additional carbon fabric produced is generally discarded. The invention may utilize carbon waste, which is the partially cured carbon warped beam fabric, or "semi-cured prepreg carbon fiber," to produce a variety of reinforced concrete products. For example, the warped beam fabric may
30 comprise carbon prepreg material which has been taken from cold storage, and allowed to cure further, but not oven cured.

In another embodiment of the invention, the carbon fiber (e.g. yarn or toe) is coated with a resinous material, such as an epoxy resin, using a standard fiber coating process which encapsulates or impregnates the fiber with sufficient coating material to provide adequate hydrophobic properties to the fiber and adequate rigidity to the fiber.

5 Preferably, the concrete is made from cement, such as Portland cement, or a mix comprising cement, such as Portland cement, and slag and/or stone and/or sand and/or other aggregates. For example, in one embodiment, slag may be present in an amount of up to about 25% of the weight of dry ingredients of the concrete mix. For example, Portland
10 cement components may include calcium (Ca), silica (Si), aluminum (Al), and iron (Fe). The calcium may be provided in the form of limestone or calcium carbonate (CaCO_3), the silicon in the form of sand (SiO_2), shale and/or clay, which may contain silicon dioxide, aluminum oxides, and iron (III) oxides, and iron ore. Aggregate may also be added to form a concrete mix, or concrete. Suitable aggregate may include stone, slag, rock, ores, and other materials.

 Concrete may be varied in composition so as to provide the desired characteristic
15 properties required for a particular application. For example, a concrete slurry in accordance with the invention may contain 10 to 18% cement, 60 to 80% aggregate, 15 to 20% water, and 0.5 to 2% carbon fibers coated with resinous material, such as epoxy resin. Entrained air in the slurry may take up to about 8%. Additionally, in accordance with the invention, concrete slurries having different percentages of components than those percentages of the example of
20 this paragraph are included in this invention.

 In a preferred embodiment of the invention, a concrete product is produced from a mixture comprising from about 97.5% - 99% by weight of cement, and from about 1% to about 2% carbon fibers coated with resinous material, such as epoxy resin. Alternately, slag
25 may be added to the mixture, with the slag component being present in an amount of up to about 25% by weight of the mixture, the fiber content preferably in an amount of from about 1% to about 2% by weight of the mixture, and the cement being present in an amount of from about 74% to 98%. In a particularly preferred embodiment, the slag is present in an amount of about 25% by weight, the cement is present in an amount of about 74% by weight, and the coated carbon fibers are present in an amount of about 1.5% by weight.

30 In a preferred embodiment of the invention, a concrete product is produced from a mixture comprising cement and "semi-cured prepreg carbon fiber". Optionally, slag may be

added to the mixture. Preferably, the semi-cured prepreg carbon fiber is uniformly dispersed throughout the mixture. For example, where the carbon fiber is pan carbon provided in a tape of a partially cured epoxy resin, the tape may be cut into small pieces, of about 2" to 3" in length, and about 1/8" to 1" in width. The prepreg carbon material is added to the cement or
5 concrete mix, and is then uniformly dispersed throughout the mixture.

Water is added to the mixture to form a slurry, and the heat of hydration heats the slurry to raise its temperature to facilitate curing of the epoxy resin of the semi-cured carbon fiber in the slurry.

The slurry may then be used by placing it into a suitable form to create a desired
10 structure or product. The curing of the resinous material, such as an epoxy, may take place while the cement is being mixed to form the slurry, and/or may also take place while the slurry is setting after it has been poured into a form or other location.

The presence of the resinous material, such as an epoxy, produces an exceptionally strong chemical bond between the carbon fibers and the cement. The invention further
15 provides bonding of the cement and carbon fibers to create strong associations between the carbon fibers and the cement. In a preferred embodiment of the invention, the carbon fibers are bonded to the cement through double bonds with cross-linking of the molecular structure.

The concrete products of the invention having coated carbon fibers therein have improved performance characteristics over prior art concrete products. For example, the
20 concrete products of the invention have improved overall strength. The overall strength is improved to provide the finished concrete product with a stronger matrix. In accordance with the invention, the inclusion of the carbon graphite fibers to cement improves the performance characteristics of the resulting concrete product with respect to degradation, deterioration, crumbling, cracking and separation, and the inclusion of such carbon graphite fibers to the
25 concrete increases the post-cracking resistance of the resulting concrete product that helps prevent deteriorated concrete from separating. The advantageous properties of the inventive concrete product also include providing the concrete with a very high impact resistance and a very high abrasion resistance. The inventive concrete material holds together under high impact force and resists spalling, resulting in a virtually shatterproof product. The inventive
30 concrete product has a substantially shatterproof performance characteristic.

The following example further illustrates the invention.

EXAMPLE 19

Component	Weight
Cement	724
Slag	310
Sand	1600
Pea gravel	1267
Resin coated carbon fiber such as semi-cured prepreg carbon fiber	57.32
Water	460
Total	lbs

The procedure set out above may be used to form a concrete mix of the invention with the dry components of the formulation of Example 19. Further, the procedure set out above
5 may be used to form a slurry of the invention with the formulation of Example 19 and a concrete product of the invention with the formulation of Example 19.

The water/cement ratio is 0.444.

Typical flexural strength for a standard concrete product not reinforced with fiber in accordance with the invention is in a range of 12-15% of the compressive strength. In
10 contrast, the ratio of flexural strength to compressive strength is 40% for the embodiment of the invention using the formulation of Example 19.

Turning to Fig. 2, there is shown a concrete product 27, in the form of a barrier, constructed in accordance with the invention. The exemplary concrete product 27 shown in the drawing comprises a body 29 having a base 31, a front face 33, a rear face 35, side faces
15 37 and 39, and an upper end surface 41. Concrete products 27 are produced using the method set out above from (a) cement, preferably Portland cement, (b) carbon fiber, such as the carbon waste, referred to as semi-cured prepreg carbon fiber, and optionally (c) slag and/or stone and/or sand and/or other aggregates.

A representative example of a concrete product in accordance with the present
20 invention was prepared by mixing Portland cement, aggregate and industrial carbon yarn (carbon fiber) made with about 45,000 filaments and coated with a 2% epoxy. The resultant

mixture was hydrated with water, and the hydrated mixture placed into a form and allowed to set. An improved concrete product was produced, having a stronger matrix.

The concrete products 27 of the present invention include Jersey barriers and terrorist barriers, including panels. Among other products which may be produced in accordance with the present invention are included: precast (non-prestressed) panels, such as for example, tilt-up wall panels, floor panels, and the like), bridge decks, post-tensioned beam anchorage zones, pre-cast beams, pipes, slab-on-grade, seismic applications, as well as airstrip pavement.

III. A concrete product in accordance with another aspect of the invention comprises concrete and carbon fibers coated with a resin, preferably a thermoplastic resin.

10 Preferably, the concrete is made from cement, such as Portland cement, or a mixture comprising cement, such as Portland cement, and silica fumes and/or slag and/or stone and/or sand and/or other aggregates. For example, in one embodiment, slag may be present in an amount of up to about 25% of the weight of dry ingredients of the concrete. For example, Portland cement components may include calcium (Ca), silica (Si), aluminum (Al), and iron
15 (Fe). The calcium may be provided in the form of limestone or calcium carbonate (CaCO_3), and the silica may be provided in the form of sand (SiO_2), shale and/or clay, which may contain silicon dioxide, aluminum oxides, and iron (III) oxides, and iron ore. Suitable aggregate may include stone, slag, rock, ores, and other materials. Alternatively, the concrete may comprise Portland cement without the addition of aggregate.

20 The carbon fibers preferably are in the form of carbon graphite fibers having a length of about 2½ inches to about 6 inches, preferably about 2 inches to about 3 inches, and more preferably about 3 inches. The carbon graphite fibers may be based, for example, upon pan carbon, pitch carbon, rayon and cotton carbon. Preferably, the carbon fibers have approximately 500,000-pound tensile strength and approximately 32-million-modulus.

25 Preferably, each carbon fiber comprises about 45,000 filaments.

Acrylic resin is used to coat the carbon fibers to increase the rigidity of (or stiffen) the carbon fibers to facilitate even dispersion of the carbon fibers in the inventive concrete slurry (and subsequently in the concrete product formed from the slurry) by preventing the fibers from balling up (piling up) in the inventive concrete slurry. Also, the acrylic coating provides
30 the carbon fiber with resistance against water absorption (e.g., provides hydrophobic properties to the carbon fiber). The acrylic coating helps control the water content in the

carbon fibers by acting as a water resistant barrier to block water in the slurry from being absorbed by the carbon fiber. Preferred methods for applying the acrylic resin to the carbon fibers include methods known in the textile industry, such as bathing, padding, spraying, foaming or applying by transfer roll, followed by curing, such as in a curing oven.

5 Application of the acrylic resin to the carbon fiber may also be accomplished by using conventional pressurized impregnation methods. Preferably, the acrylic resin is coated on the carbon fibers in a sufficient amount to provide adequate coating on and impregnation of the acrylic resin into the carbon fibers to provide adequate hydrophobic properties to the carbon fiber to guard against the absorption by the carbon fiber of too much water from the slurry, to
10 provide adequate rigidity to the carbon fiber to prevent pilling up (balling up) of the carbon fiber to facilitate even dispersion of the carbon fibers in the concrete slurry, and to facilitate bonding between the carbon fiber and the concrete in the concrete matrix of the concrete product. A preferable acrylic content is from 8% to 20% (and preferably about 17%) by weight of the coated carbon fiber.

15 Preferably, the acrylic coated carbon fibers are slightly flattened, preferably by the use of a roller. For example, carbon fibers may be moved through an acrylic bath to coat and impregnate the carbon fibers with an acrylic resin, and the acrylic coated carbon fibers may be flattened by moving them through a roller positioned in the acrylic bath. This flattening of the fibers improves the dispersability of the carbon fibers in the concrete slurry, as well as in the
20 dry concrete mix of the invention..

After the curing step, the acrylic coated carbon fiber is cut, preferably using a chopper, into the desired length (about 2½ inch to about 6 inch lengths, with about 2½ inch to about 3½ inch lengths being more preferred, and about 3 inch lengths being even more preferred) for use.

25 The acrylic coating on the carbon fibers increases the rigidity of the carbon fibers, which helps prevent balling up or pilling up of the fibers. As a result, the carbon fibers, rather than balling up (piling up), disperse in an extended non-balled up form throughout the inventive slurry and the inventive mix. The flattening of the acrylic coated carbon fibers helps expose more of the filaments of the carbon fiber, which leads to greater penetration of the
30 acrylic resin into the carbon fiber. The acrylic coating also provides a water resistance to the carbon fiber to help prevent it from picking up moisture when placed in the concrete slurry.

It is believed that the acrylic resin opens up the carbon fiber and the filaments thereof to permit the cement to penetrate into the interstices of the carbon fibers and the filaments thereof to form strong bonds between the cement and the carbon fiber.

5 In a preferred embodiment, the acrylic coated carbon fibers are evenly dispersed throughout the inventive concrete slurry to obtain a concrete matrix in the concrete product formed from the slurry having the acrylic coated carbon fibers evenly dispersed throughout it, thereby, facilitating the prevention of cracking and separation of the concrete matrix.

10 In a preferred embodiment of the invention, the inventive concrete product comprises concrete having about 2½ inch long to about 6 inch long (more preferably about 2½ inch long to about 3½ inch long, and even more preferably about 3 inch long) acrylic coated carbon fibers evenly dispersed throughout the concrete matrix of the concrete, and small (e.g., nano sized) silica fumes evenly dispersed throughout the concrete matrix of the concrete, and optionally slag and/or stone and/or sand and/or other aggregates. The nano-size silica fumes fill the small voids in the concrete matrix of the concrete product, thereby decreasing the
15 water permeability of the concrete product. By decreasing the water permeability of the concrete product, the concrete product becomes more resistant against water degradation. Further, by decreasing the water permeability of the concrete product, the concrete product becomes more resistant against any metal reinforcement rods (i.e., rebar) or mesh contained in the concrete product weakening due to rusting.

20 The inventive concrete slurry may be prepared by mixing (a) the cement, (b) the acrylic coated carbon fibers, (c) water, and optionally (d) silica fumes and/or slag and/or stone and/or sand and/or other aggregates together, preferably in a cement mixer. Preferably the acrylic coated fibers are uniformly dispersed throughout the slurry. Preferably, water is added to the cement and any of the optional components to form a wet mixture in the cement mixer,
25 and then the acrylic coated carbon fibers are fed into the wet mixture, slowly at first and then at a faster rate, until the carbon fibers have been evenly dispersed throughout the wet mixture. A preferred water/cement ratio for the slurry is 0.444. After placing the slurry in a form or the like, it may be allowed to set to form the inventive concrete product.

30 The invention also includes a concrete mix comprising (a) cement, preferably Portland cement (b) acrylic coated carbon fibers having a length of about 2½ inches to about 6 inches, preferably about 2½ inches to about 3½ inches, and more preferably about 3 inches, and

optionally (c) silica fumes and/or slag and/or stone and/or sand and/or other aggregates. Preferably, the acrylic coated carbon fibers are uniformly dispersed throughout the mix. In a preferred embodiment of the invention, concrete products are produced from the inventive mix by gradually stirring water into the mix, preferably using a cement mixer, to form a cement slurry, mixing the slurry to adequately disperse the components of the mix throughout the slurry, placing the slurry in a form or the like, and letting the concrete set.

Concrete may be varied in composition so as to provide the desired characteristic properties required for a particular application. For example, a concrete slurry in accordance with the invention may contain 10 to 18% cement, 60 to 80% aggregate, 15 to 20% water, and 0.5 to 2% carbon fibers. Entrained air in the slurry may take up to about 8%. Additionally, in accordance with the invention, concrete slurries having different percentages of components than those percentages of the example of this paragraph are included in this invention.

In a preferred embodiment of the invention, a concrete product is produced from a mixture comprising from about 97.5% - 99% by dry weight of cement, and from about 1% to about 2% dry weight of acrylic coated carbon fibers. Alternately, slag may be added to the mixture, with the slag component being present in an amount of up to about 25% by dry weight of the mixture, the fiber content preferably in an amount of from about 1% to about 2% by dry weight of the mixture, and the cement being present in an amount of from about 74% to 98% by dry weight of the mixture. In a particularly preferred embodiment, the slag is present in an amount of about 25% by dry weight, the cement is present in an amount of about 74% by dry weight, and the carbon fibers are present in an amount of about 1.5% by dry weight. In preferred embodiments of the invention, the acrylic coated carbon fibers are provided in a range of about 1% to about 2% by weight of the concrete mix or concrete product, with 1.5% by weight of the concrete mix or concrete product being more preferred.

Under tensile stresses, the fibers bridge the cracks and restrain the widening of the concrete by providing pullout resistance. The fibers lead to the improvement of the post peak ductility and toughness of the material. The formation of cracked systems in the cement is minimized or prevented, thus increasing the tensile strength on the overall toughness of the inventive composite material. The carbon fibers do not rust, have super tensile strength, and are inert to chemicals.

The concrete products of the invention have improved performance characteristics over conventional concrete products. For example, the concrete products of the invention have improved overall strength. The overall strength is improved to provide the finished concrete product with a stronger matrix. In accordance with the invention, the inclusion of the carbon graphite fibers to cement improves the performance characteristics of the resulting concrete product with respect to degradation, deterioration, crumbling, cracking and separation, and the inclusion of such carbon graphite fibers to the concrete increases the post-cracking resistance of the resulting concrete product that helps prevent deteriorated concrete from separating. The advantageous properties of the inventive concrete product also include providing the concrete with a very high impact resistance and a very high abrasion resistance. The inventive concrete material holds together under high impact force and resists spoiling, resulting in a virtually shatterproof product. The inventive concrete product has a substantially shatterproof performance characteristic.

The method of reinforcing the concrete comprises the steps of mixing (a) cement, (b) acrylic coated carbon fibers having a length of about 2½ inches to about 6 inches (more preferably about 2½ inches to about 3½ inches, and even more preferably about 3 inches) (c) water, and optionally (d) silica fumes and/or slag and/or stone and/or sand and/or other aggregates together to form a slurry wherein the carbon fibers are dispersed evenly throughout the slurry, and letting the slurry set in a form to cure the cement and form bonds between the cement and the carbon fibers, thereby obtaining reinforced concrete.

In each of the following examples, the cement, the acrylic coated carbon fibers, and any optional components such as silica fumes, slag, stone, sand, and/or other aggregates are mixed with sufficient water to form the concrete slurry. Preferably, using a cement mixture, water is added to the cement and any of the optional components (i.e., silica fumes, slag, stone, sand, and/or other aggregates) to form a wet mixture in the cement mixer, and then the acrylic coated carbon fibers are fed into the wet mixture, slowly at first and then at a faster rate, until the carbon fibers have been evenly dispersed throughout the wet mixture.

Alternatively, a dry concrete mix may be prepared by mixing the cement, the acrylic coated carbon fibers, and any optional components (i.e., silica fumes, slag, stone, sand, and/or other aggregates) together. Then, preferably using a cement mixer, sufficient water is gradually stirred into the dry mix to form the cement slurry.

The cement slurry is placed in a form or the like, and is allowed to set to form the inventive concrete product. Concrete products are produced using the method set out above from (a) cement, preferably Portland cement, (b) carbon fiber coated with an acrylic resin, and optionally (c) silica fumes and/or slag and/or stone and/or sand and/or other aggregates. The following are some of the preferred examples of the cement mixes for concrete products of the invention:

EXAMPLE 1.1

Component	Weight	Percent by Weight
Cement	800 lbs	98.5 %
2½ in. to 3½ in. long acrylic coated carbon fibers	12 lbs	1.5 %
Total	812 lbs	100 %

EXAMPLE 1.2

Component	Weight	Percent by Weight
Cement	800 lbs	98.5 %
2½ in. to 6 in. long acrylic coated carbon fibers	12 lbs	1.5 %
Total	812 lbs	100 %

EXAMPLE 1.3

Component	Weight	Percent by Weight
Cement	800 lbs	98.5 %
3 in. long acrylic coated carbon fibers	12 lbs	1.5 %
Total	812 lbs	100 %

EXAMPLE 1.4

Component	Weight	Percent by Weight
Cement	782 lbs	97.75 %
2½ in. to 3½ in. long acrylic coated carbon fibers	12 lbs	1.5 %
Silica fumes	6 lbs	0.75 %

Total	800 lbs	100 %
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EXAMPLE 1.5

Component	Weight	Percent by Weight
Cement	782 lbs	97.75 %
2½ in. to 6 in. long acrylic coated carbon fibers	12 lbs	1.5 %
Silica fumes	6 lbs	0.75 %
Total	800 lbs	100 %

EXAMPLE 1.6

Component	Weight	Percent by Weight
Cement	782 lbs	97.75 %
3 in. long acrylic coated carbon fibers	12 lbs	1.5 %
Silica fumes	6 lbs	0.75 %
Total	800 lbs	100 %

5

EXAMPLE 1.7

Component	Weight	Percent by Weight
Cement	600 lbs	73.9 %
Slag	200 lbs	24.6 %
2 1/2 in. to 3 1/2 in. long acrylic coated carbon fibers	12 lbs	1.5 %
Total	812 lbs	100 %

EXAMPLE 1.8

Component	Weight	Percent by Weight
Cement	600 lbs	75 %
Slag	182 lbs	22.75 %
2 1/2 in. to 3 1/2 in. long acrylic coated carbon fibers	12 lbs	1.5 %
Silica fumes	6 lbs	0.75 %
Total	800 lbs	100 %

EXAMPLE 1.9

Component	Weight	Percent by Weight
Cement	600 lbs	75 %
Slag	182 lbs	22.75 %
6 in. long acrylic coated carbon fibers	12 lbs	1.5 %
Silica fumes	6 lbs	0.75 %
Total	800 lbs	100 %

EXAMPLE 1.10

Component	Weight	Percent by Weight
Cement	600 lbs	75 %
Slag	182 lbs	22.75 %
3 in. long acrylic coated carbon fibers	12 lbs	1.5 %
Silica fumes	6 lbs	0.75 %
Total	800 lbs	100 %

5

EXAMPLE 1.11

Component	Weight	Percent by Weight
Cement	600 lbs	16 %
Slag	200 lbs	5 %
2 1/2 in. to 3 1/2 in. long acrylic coated carbon fibers	56 lbs	1 %
Stone	1,864 lbs	49 %
Sand	1,108 lbs	29 %
Total Weight	3,828 lbs	100 %

EXAMPLE 1.12

Component	Weight	Percent by Weight
Cement	600 lbs	16 %
Slag	200 lbs	5 %
3 in. long acrylic coated carbon fibers	56 lbs	1 %
Stone	1,864 lbs	49 %
Sand	1,108 lbs	29 %
Total Weight	3,828 lbs	100 %

EXAMPLE 1.13

Component	Weight	Percent by Weight
Cement	600 lbs	15.7 %
Slag	171.5 lbs	4.5 %
6 in. long acrylic coated carbon fibers	67.5 lbs	1.8 %
Stone	1,864 lbs	48.9 %
Sand	1,108 lbs	29.1 %
Total	3,811 lbs	100 %

5

EXAMPLE 1.14

Component	Weight	Percent by Weight
Cement	600 lbs	15.7 %
Slag	171.5 lbs	4.5 %
2 1/2 in. to 3 1/2 in. long acrylic coated carbon fibers	39 lbs	1 %
Silica fumes	28.5 lbs	0.8 %
Stone	1,864 lbs	48.9 %
Sand	1,108 lbs	29.1 %
Total	3,811 lbs	100 %

EXAMPLE 1.15

Component	Weight	Percent by Weight
Cement	600 lbs	15.7 %
Slag	171.5 lbs	4.5 %
2 1/2 in. to 3 1/2 in. long acrylic coated carbon fibers	39 lbs	1 %
Micron sized carbon graphite fibers	28.5 lbs	0.8 %
Stone	1,864 lbs	48.9 %
Sand	1,108 lbs	29.1 %
Total	3,811 lbs	100 %

EXAMPLE 1.16

Component	Weight	Percent by Weight
Cement	600 lbs	15.7 %
Slag	171.5 lbs	4.5 %
2 1/2 in. to 3 1/2 in. long acrylic coated carbon fibers	53.24 lbs	1.4 %
Silica fumes	14.25 lbs	0.4 %
Stone	1,864 lbs	48.9 %
Sand	1,108 lbs	29.1 %
Total	3,811 lbs	100 %

5

EXAMPLE 1.17

Component	Weight	Percent by Weight
Cement	600 lbs	15.7 %
Slag	148.53 lbs	3.9 %
2 1/2 in. to 3 1/2 in. long acrylic coated carbon fibers	76.22 lbs	2.0 %
Silica fumes	14.25 lbs	0.4 %
Stone	1,864 lbs	48.9 %
Sand	1,108 lbs	29.1 %
Total	3,811 lbs	100 %

The various concrete products of the present invention should have an advantage over traditional concrete without the reinforcement fibers in many of the following properties: fatigue resistance, ductility, impact resistance, durability, toughness, energy absorption, crack control (shrinkage and hopefully structural applications), reduction of steel reinforcement, bond length (as opposed to other short fiber types) and creep reduction. Therefore, the various applications of concrete products of the present invention include those Jersey barriers and terrorist barriers, including panels. Among other products which may be produced in accordance with the present invention are included: precast (non-prestressed) panels, such as for example, tilt-up wall panels, floor panels, and the like), bridge decks, post-tensioned beam anchorage zones, pre-cast beams, pipes, slab-on-grade, seismic and security safeguard in new structures, high-performance thin architectural elements, as well as airstrip pavement. The other applications included industrial and non-industrial, consumer, and warehouse floor slabs, pavements, slope stabilization, tunnel linings, upgrades to existing structures and septic tanks, vaults, pipes, block, and other specialty pre-cast shapes.

In another preferred embodiment of the invention, the carbon fibers are about 2½ inches to about 3½ inches in length that are evenly dispersed throughout the concrete matrix. Carbon graphite fibers having the length of about 2 ½ inches to about 3 ½ inches that are evenly dispersed in the concrete matrix prevent cracking and separating of the concrete matrix. Under tensile stresses, the fibers bridge the cracks and restrain the widening of the concrete by providing pullout resistance. The fibers lead to the improvement of the post peak ductility and toughness of the material. The formation of cracked systems in the cement is prevented, thus increasing the tensile strength on the overall toughness of the inventive composite material. The carbon fibers do not rust, have super tensile strength, and are inert to chemicals. The fibers having a length of about 2 ½ inches to about 3 ½ inches, when not provided with a coating, may be penetrated by the cement to form a bond that locks the cement to the fibers.

IV. The present invention also provides gypsum products containing a combination of gypsum and reinforcement carbon fibers and/or nano carbon fibers. The combination improves the strength, flexibility, toughness and weather or environmental properties of the gypsum products.

In an embodiment of the invention, a gypsum product contains gypsum and reinforcement carbon fibers, preferably in the form of milled and microscopic chopped carbon graphite fibers and/or chopped carbon graphite fibers having a length of about 2 ½ inches to about 3 ½ inches. The graphite fibers may be based, for example, upon pan carbon, pitch carbon, rayon and cotton carbon. Preferably, the carbon may have approximately 500,000-pound tensile strength and approximately 32-million-modulus.

In a preferred embodiment of the invention, the carbon fiber lengths are of nano-sized lengths or nano-fumes, which is about one billionth of a meter (10^{-9} m) or about 0.000000001 meters (0.1 nm) to 200 microns. The gypsum products of the invention to which nano fibers are added have improved properties.

Provided below are examples of gypsum mixes containing carbon fibers:

EXAMPLE 1.1.1

GROUT FORMULA

Component	Percent by Weight
Gypsum	50%
Sand	48 ½%
Nano carbon fibers	1 ½%
	100%

The components are mixed together, and to the dry mixture of components is added water (about 20% by weight) to form a grout composition ready to be used that has greater strength, flexibility, toughness, and weather or environmental resistance properties than a grout not having nano-fibers of the invention. The nano-fibers comprise chopped carbon graphite fibers.

EXAMPLE 1.1.2

WALLBOARD FORMULA

Component	Percent by Weight
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Gypsum	50%
Nano carbon fibers	1%
2 ½ inch to 3 ½ inch carbon fibers	0.5%
Sand	Balance of ingredients
Total	100%

The components are mixed together, and to the dry mixture of components is added water (about 20% by weight) to form a wall board composition ready to be used that has greater strength, flexibility, toughness, and weather or environmental resistance properties than a wallboard composition not having nano-fibers and/or reinforcement fibers having a length of about 2 ½ inches to about 3 ½ inches in accordance with the invention. The fibers comprise chopped carbon graphite fibers.

EXAMPLE 1.1.3

Component	Percent by Weight
Cement	30%
Sand	30%
Gypsum	30%
Carbon graphite fibers	1.5%
Chemicals for flow and defoaming (superplasticizer, defoamer, and latex)	Balance of ingredients
Total	100%

The components are mixed together, and to the dry mixture of components is added water (about 20% by weight) to form a cement/gypsum composition ready to be used to form a cement/gypsum composite for use in the building trade that has the advantageous properties of the invention. The fibers may be either nano-fibers and/or fibers having the length between 2 ½ inches and 3 ½ inches.

WORKING EXAMPLES

The following working examples further illustrate the present invention. These working examples, however, should not be constructed as in any way limiting its scope. The examples below are carried out using standard techniques that are well known and routine to those of skill in the art, except where otherwise described in detail.

1. Compression and flexural strengths of concrete products containing 2 ½ in. to 3 ½ inch epoxy coated reinforcement carbon fibers

Compression and flexural strengths of concrete product containing the components listed in Table 1 below were tested.

Table 1. Concrete mixture containing reinforcement carbon fibers

Component	Weight	Percent by Weight
Cement	600 lbs	16%
Slag	200 lbs	5%
2½ in. to 3½ in. long reinforcement fibers	39 lbs	1%
Stone	1,864 lbs	49%
Sand	1,108 lbs	29%
Total Weight:	3,811 lbs	100%

The components were mixed together, and to the dry mixture of components water and a superplasticizer Sikament 2000 were added. The fibers comprised chopped carbon graphite. Mixing took place in a commercial blender such as a rotary action mixer. The results obtained are as follows:

Total:	Compression	8,600 lbs
	Flexibility	2,110 lbs

In one preferred embodiment of the invention, the carbon fiber lengths are of nano-sized lengths or nano-fumes, which is about one billionth of a meter (10^{-9} m) or about 0.000000001 meters (0.1 nm) to 400 microns or about 1 nm to 200 microns. The concrete product comprises concrete plus the addition of about less than 10 % nano fibers. The concrete products of the invention to which nano fibers have been added have improved properties. For example, the concrete products preferably increase the flexibility of the concrete as well

as an increase in the deflection of the concrete. For example, when the nano-sized carbon fibers are present at a concentration of about 0.25% to 2% by weight of nano fiber content to concrete content, the concrete flexibility is increased by about 300% and the concrete deflection is increased by about 500%. As little as 0.25% concentration of the carbon graphite fibers in the concrete mix imparts beneficial improvements in strength to the resultant concrete products, and aids in minimizing some or all of the deficiencies observed with traditional concrete products.

2. Compression and Flexural strengths of concrete products containing nano-sized carbon fibers

Milled and chopped carbon graphite nano fibers (0.1 to 400 microns) were used in a cement mix as listed in Table 2 below:

Table 2. Concrete mixture containing nano-sized carbon graphite fibers

Component	Weight	Percent by Weight
Cement	600 lbs	16%
Slag	200 lbs	5%
Nano Fibers	56 lbs	1%
Stone	1,864 lbs	49%
Sand	1,108 lbs	29%
Total Weight:	3,828 lbs	

The components were mixed together, and to the dry mixture of components was added water and a superplasticizer. The nano fibers comprised chopped carbon graphite. Mixing took place in the drum of a cement truck. The results obtained are as follows:

Total:	Compression	9,120 lbs
	Flexibility	1,945 lbs

The flex test results were measured at 400% increase over the standard base.

3. Compression and Flexural strengths of concrete products containing epoxy coated reinforcement carbon fibers (2 ½ in. to 3 ½ in)

Compression and flexural strengths of concrete product containing the components listed below were tested.

<u>Mix Components (lb/yd³)</u>	
Cement SF	724
NewCem	310

Sand	1600
Pea Gravel	1267
Fibers (AISC)	57.32
Water	460
Water/Cement Ratio	0.444

	Compressive Strength (psi)	Flexural Strength (psi)	Flexural Strength as a percent of Compressive Strength
Seven Day	2730	2000	74
Twenty-eight Day	4825	2755	57

The mixing cycle for this design was in accordance with ASTM C192. Flexural strength beams were consolidated by use of a vibratory table. Typical flexural strength for a standard concrete product was in the range of 12 to 15% of compressive strength.

6. Compression and Flexural strengths of concrete products containing urethane coated reinforcement carbon fibers (2 ½ in. to 3 ½ in)

- 10 Compression and flexural strengths of concrete product containing the components listed below were tested.

	Mix Components (lb/yd ³)	
	Cement SF	724
	NewCem	310
15	Sand	1600
	Pea Gravel	1267
	Fibers (Mach 1 with Urethane)	57.32
	Water	460
20	Water/Cement Ratio	0.444

	Comprehensive Strength (psi)	Flexural Strength (psi)	Flexural Strength as a percent of Comprehensive Strength
Three Day	3490	2740	78
Seven Day	3990	2560	
	4590	2830	
Averages	4290	2695	63
Fourteen Day	4930	2460	50
Twenty-eight Day	6150	3320	54
Fifty-six Day			

The mixing cycle for this design was in accordance with ASTM C 192. Flexural strength beams were consolidated by use of a vibratory table. Typical flexural strength is in the range of 12 to 15% of compressive strength (based on formula 9-10 of ACI 318-02).

7. Demonstration of Blast Resistance of concrete containing reinforcement carbon fibers

For purposes of the description of this experiment, the concrete containing the reinforcement carbon fibers is also referred to herein as a safe concrete. The majority of applications with carbon fibers in concrete have focused on short, discontinuous fibers. These fibers can be effective in bridging small surface cracking, but typically do not produce significant gains in flexural strength or spalling resistance. The safe concrete material incorporated 3 inch long carbon fiber tape (cured to C-stage described above using epoxy resin). The carbon fibers were mixed directly into the concrete during mixing and required no special equipment for placing. The fibers could be dispersed evenly in the concrete matrix and good workability was retained.

The blast testing described in this example confirms that safe concrete can be safely used for applications requiring blast resistance. Specimens consisted of reinforced concrete slabs with dimensions of 6'x 6'x 6.5". These specimens provided a representative size for a number of potential applications. All specimens contained mild steel (grade 60) reinforcement. Specimens were designed for 50 pounds of TNT at a standoff distance of 6'. The reinforcement consisted of two mats of #4 bars in each direction, spaced at 6" on center. Bars were hooked to provide adequate development. #3 ties were provide at 12" spacing (alternating bar junctions). Specimens were supported on all four sides. Two sides had mild rotational resistance to keep the specimen from moving off of the supports.

Test specimens consisted of 2 control specimens (PL-1 and PL-2) and 2 reinforcement carbon fiber specimens (safe concrete F-A and F-B). The matrix of test variables is shown in Table 1. The control specimens are a standard concrete mix with a target compressive strength of 4000 psi. The safe concrete specimens are a standard concrete mix incorporating a silica fume blend cement and ground granulated blast furnace slag with the addition of 1.5% fibers by volume (or approximately 0.87% by weight). Both the control and safe concrete mixes had a 1/2" maximum aggregate size. The two control specimens were identical. The two safe concrete specimen mixes were identical expect that the fiber coating was slightly adjusted. Fiber Type A and B both had coating to enable the fibers to

disperse in the concrete. Type B also was more workable. However, as described further below, both fiber types showed comparable performance.

The first control specimen was tested with 50 pounds of TNT at a standoff distance of 6' to the center of the charge. Additional tests used higher charge weights and lower standoff distances based on specimen performance. Certain specimens were subjected to an additional hit after evaluation of the damage from the first hit. Table 1 indicates the charge weight and distance for each of the specimens tested. Detailed information and performance is given in the following sections.

Table below concerning specimen test matrix includes a scaled range, defined as follows:

$$Z = \frac{R}{W^{1/3}} \quad \text{where R is the distance to the center of the charge in feet and W is the TNT weight in pounds}$$

Table : Specimen Test Matrix

Specimen	Description	Hit #	Scaled Range	TNT Distance (ft)	Weight (lb)
PL-1	Standard Concrete	1	1.63	6	50
PL-2	Standard Concrete	1	1.42	6	75
		2	0.76	3.2	75
F-A (Epoxy coated fiber)	Safe concrete, fiber type A	1	1.42	6	75
		2	0.76	3.2	75
F-B (Acrylic coated fiber)	Safe concrete, fiber type B	1	0.76	3.2	75

Components of PL-1 and PL-2

Component	lb/cu yd (at SSD)
cement	658.00
fine aggregate	1116.00
coarse aggregate	1852.00
water	264.50

Components of PL-1 and PL-2

Item	lb/cu yd (at SSD)
cement	723.80
slag	310.20
fine aggregate	1059.45
coarse aggregate	1267.17
water	351.59
carbon fibers	33.41

Both PL-1 and PL-2 showed spalling and cracking. Due to the conservative nature of the TM5-1300 design, PL-1 did not experience extreme damage. After the blast, PL-1 showed cracking through the depth visible on the sides. The top surface exhibited mild spalling and bottom (tensile) side showed cracking. Cracking was extensive on the bottom surface with some minor spalling. The top surface damage in PL-2, after the blast, was significantly greater than seen in PL-1. Significant full-depth cracks were evident along the sides of the specimen. Cracking was extensive on the bottom surface with some spalling. The PL-2 control specimen was subjected to an additional blast hit of 75 pounds of TNT at 3.2' standoff distance. This scaled range of 0.76 is equivalent to 500 pounds of TNT at a 6' standoff distance. The specimen was already showing significant damage from hit 1, but the additional hit was done to provide a comparison to a safe concrete specimen under the same double hit. The slab (PL-2) was completely destroyed with primarily only the reinforcing cage intact. The reinforcement was buckled where visible in the bottom mat. The majority of the concrete was reduced to rubble and large pieces of concrete were scattered about the test site.

The safe concrete F-A specimen was subjected to the same two hits as the PL-2 control specimen. The first hit was 75 pounds of TNT at a 6' standoff distance. After the blast, the specimen showed no apparent top surface damage and no cracking on the sides. The bottom surface had a small number of cracks and no appreciable spalling. The condition of the specimen was in very good condition after the blast and significantly improved over the control specimen. The safe concrete F-A specimen was subjected to an additional blast hit of 75 pounds of TNT at 3.2' standoff (scaled range of 0.76). After the blast, the top surface remained in excellent condition. The sides showed cracking at the surface. The bottom side of the slab showed cracking and some areas of spalling. The specimen remained intact with significantly better performance than the control specimen. In areas where the concrete did

spall, the weakness was at the steel-concrete interface. The reinforcement was buckled where visible in the bottom mat. The concrete spalls between the steel reinforcement mat were held together by the reinforcement carbon fiber and were no concrete shrapnel was scattered about the test site. The performance of the specimen under the series of two severe hits was
5 excellent.

The safe concrete F-B specimen was hit directly with a single blast hit of 75 pounds of TNT at 3.2' standoff (scaled range of 0.76 and equivalent to 500 pounds of TNT at 6'). The intention of this test was to observe the behavior of a safe concrete specimen with the alternate carbon fiber coating under a severe blast load. After the blast, the top surface
10 exhibited some very shallow spalling of concrete between fibers. The sides showed cracking. The bottom side of the slab had spalling and the steel reinforcement was buckled where visible. The spalls consisted of primarily shallow pieces that were forced off by the heavily deformed the metal reinforcement. The spalled pieces remained held together by the fibers and were not scattered at the test site. The performance of the specimen under this severe
15 blast with a scaled range of 0.76 was excellent. Thus, it has been demonstrated that performance of both safe concrete specimens under severe blast loading (scaled range 0.76) was excellent. The safe concrete clearly performed better than the standard concrete with improved structural performance as well as significantly reduced spalling. Concrete shrapnel was scattered around the test site in the test of the control panel while the safe concrete panel
20 was shatter resistant.

All publications, patents and patent applications mentioned in the specification are indicative of the level of those skilled in the art to which this invention pertains. All publications, patents and patent applications are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually
25 indicated to be incorporated by reference. While the foregoing invention has been described with a reference to specific embodiments, it will be obvious to those of ordinary skill in the art that variations in these methods and compositions may be used and that it is intended that the invention may be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications encompassed within the spirit and scope of the
30 invention as defined by the claims.

WHAT IS CLAIMED IS:

1. An engineered fiber comprising a fiber made of plurality of filaments, wherein the fiber is a texturized fiber.

5 2. The engineered fiber of claim 1, wherein the fiber is coated with a resin.

3. The engineered fiber of claim 2, wherein the fiber is one selected from the group consisting of: carbon fibers, glass fibers, nylon fibers and polyvinyl alcohol (PVA) fibers.

10 4. The engineered fiber of claim 2, wherein the fiber is coated with a thermoplastic resin or a thermosetting resin or a combination thereof.

5. The engineered fiber of claim 4, wherein the resin is present in the amount of between about 2 and about 30% solids per dry weight of said fiber.

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6. The engineered fiber of claim 2, wherein the fiber has an average density that is less than the density of high tensile steel fiber of equal mass.

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7. The engineered fiber of claim 2, wherein the fiber has an ability to form stronger interface bonds with other component in a mix as compared to control fibers that are non-texturized.

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8. The engineered fiber or claim 2, wherein the resin is at least one selected from the group consisting of an epoxy resin or an acrylic resin.

9. A kit comprising a texturized fiber coated with a resin.

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10. The engineered fiber of claim 9, wherein the fiber is one selected from the group consisting of: a carbon fiber, a glass fiber, a nylon fiber and a polyvinyl alcohol (PVA) fiber.

11. A method of preparing a reinforcement fiber comprising the steps of:

- (a) texturing a fiber;
- (b) providing molten thermoplastic resin containing composition;
- (c) contacting the fiber with said composition;
- (d) drying the fiber after step (c) to obtain the reinforcement fiber.

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12. The method of claim 11, wherein the fiber is texturized by advancing a continuous yarn through a converging nip between a pair of opposing rollers.

10 13. The method of claim 11, wherein the molten thermoplastic composition has a viscosity ranging from about 1 cps to about 100 cps.

14. The method of claim 11, wherein, said contacting the fiber is by immersing the fiber in a bath of molten thermoplastic composition.

15 15. The method of claim 11, wherein contacting the fiber with said composition is by releasing said composition from a coating device at a temperature of less than about 150°C.

17. The method of claim 11, wherein said resin is present in an amount of between about 10% and about 20% solids per dry weight of the fiber.

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18. The method of claim 11, wherein said resin is an acrylic resin and present in amount of about 16% by weight.

19. A method of preparing an engineered a fiber in a fabric form comprising

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- (a) texturizing the fiber, where in the fiber is in the form of yarns;
- (b) aligning individual yarn side by side on a roller to form a tape of a given width and having a first surface and a second surface;
- (c) treating the aligned yarns with a water dispersible thermosetting resin; and
- (d) curing the resin treated yarns thereby forming the fiber in a fabric form.

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20. The method of claim 19, wherein the aligned yarn is treated by placing, on the first surface, a release paper containing the thermosetting resin facing the first surface.
21. The method of claim 19, wherein the thermosetting resin has a viscosity ranging from about 100 cps to about 1000 cps in step (c).
22. The method of claim 19, wherein the resin being present in an amount of between about 2 and 30% solids per dry weight of the fiber.
23. The method of claim 19, wherein the curing step is accomplished by heating the fiber.
24. The method of claim 23, wherein the heating takes place at about 50°C to about 150°C.
25. The method of claim 3, wherein the resin is an epoxy resin.
26. A concrete product comprising concrete having texturized carbon fibers dispersed therein, the carbon fibers having an acrylic resin coating.
27. The concrete product of claim 1, the carbon fibers having a unidirectional fiber configuration.
28. The concrete product of claim 1, the carbon fibers having a length of 1 inch to 6 inches.
29. The concrete product of claim 1, the carbon fibers having a length of 2 ½ inches to 3½ inches.
30. The concrete product of claim 1, the carbon fibers having a length of 3 inches.
31. The concrete product of claim 1, further including silica fumes.

32. The concrete product of claim 1, further including aggregate.

33. The concrete product of claim 1, further including slag.

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34. The concrete product of claim 1, wherein carbon fibers are provided in the form of a carbon yarn comprising a plurality of filaments.

10 35. A dry concrete mix comprising concrete and carbon fibers, the carbon fibers having an acrylic coating.

36. The dry concrete mix of claim 35, the carbon fibers having a unidirectional fiber configuration.

15 37. The dry concrete mix of claim 35, the carbon fibers having a length of 1 inch to 6 inches.

38. The dry concrete mix of claim 10, the carbon fibers having a length of 2½ inches to 3½ inches.

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39. The dry concrete mix of claim 10, the carbon fibers having a length of 3 inches.

40. The dry concrete mix of claim 10, further including silica fumes.

25 41. The dry concrete mix of claim 10, further including aggregate.

42. The dry concrete mix of claim 10, further including slag.

30 43. The dry concrete mix of claim 10, wherein carbon fibers are provided in the form of a carbon yarn comprising a plurality of filaments.

44. A method of reinforcing concrete, comprising the steps of mixing cement, texturized carbon fibers coated with an acrylic coating, and water together to form a slurry, and letting the slurry set to cure the cement and form bonds between the cement and the carbon fibers, thereby obtaining reinforced concrete.

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45. The method of claim 44, the carbon fibers having a unidirectional fiber configuration.

46. The method of claim 44, the carbon fibers having a length of 1 inch to 6 inches.

10 47. The method of claim 44, the carbon fibers having a length of 2½ inches to 3½ inches.

48. The method of claim 44, the carbon fibers having a length of 3 inches.

15 49. The method of claim 44, further including mixing silica fumes with the cement, the carbon fibers, and the water to form the slurry.

50. The method of claim 44, further including mixing aggregate with the cement, the carbon fibers, and the water to form the slurry.

20 51. The method of claim 44, further including mixing slag with the cement, the carbon fibers, and the water to form the slurry.

52. The method of claim 44, wherein carbon fibers are provided in the form of a carbon yam comprising a plurality of filaments.

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53. A product comprising gypsum and carbon fibers dispersed therein, wherein the carbon fibers are texturized and resin coated.

30 54. The product of claim 53, wherein the carbon fibers have a unidirectional fiber configuration.

55. The product of claim 53, wherein the carbon fibers have a length of 1 inch to 6 inches.

55. The product of claim 53, wherein the carbon fibers have a length of 2 ½ inches to 3½ inches.

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56. The product of claim 53, wherein the carbon fibers have a length of 3 inches.

57. The product of claim 53, further including silica fumes.

10 58. The product of claim 53, wherein gypsum is present in an amount of from about 30% to 50% by weight.

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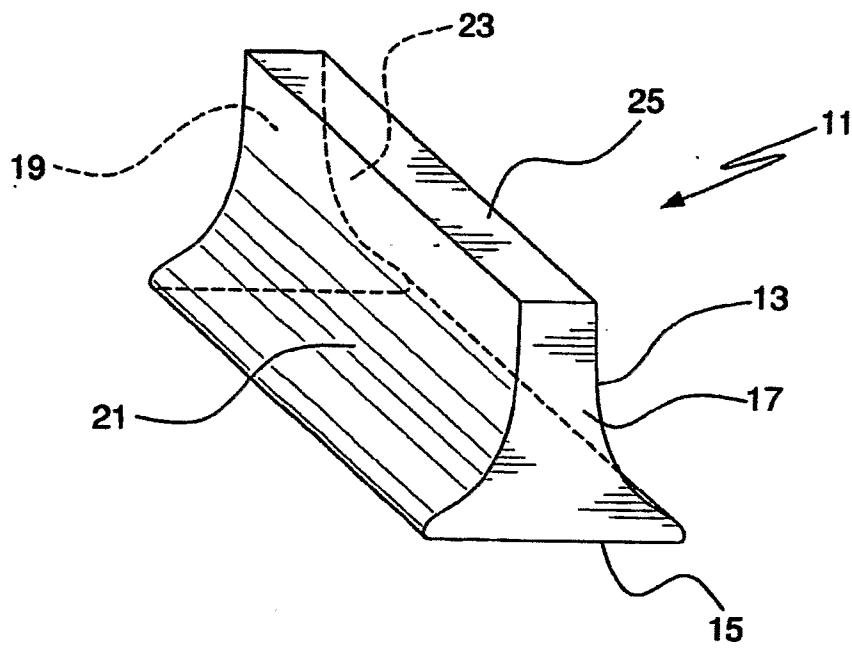


FIG. 1

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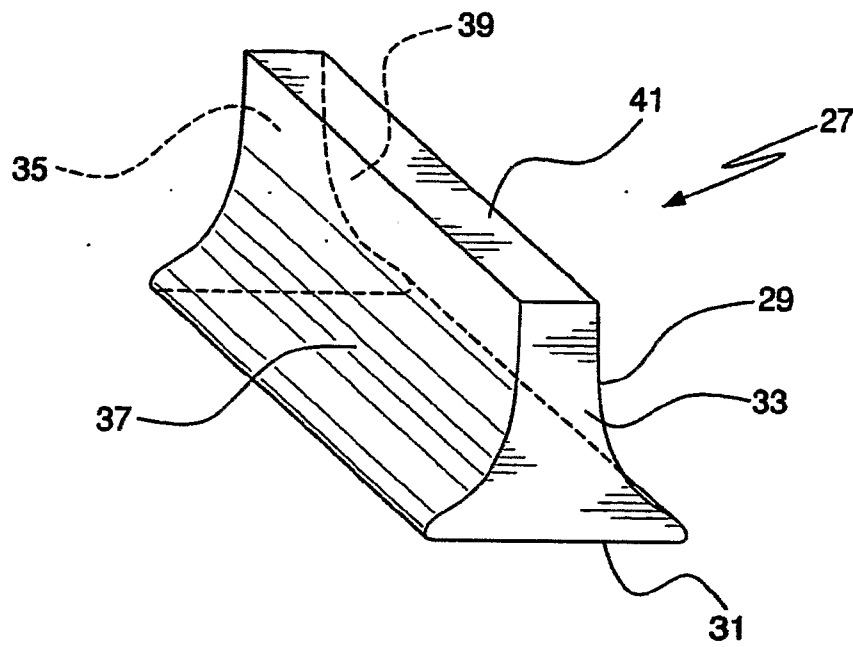


FIG. 2