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(54) **VIBRATION RESISTANT REINFORCEMENT FOR BUILDINGS**

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(58) **Field of Classification Search** 52/167.1–167.9
See application file for complete search history.

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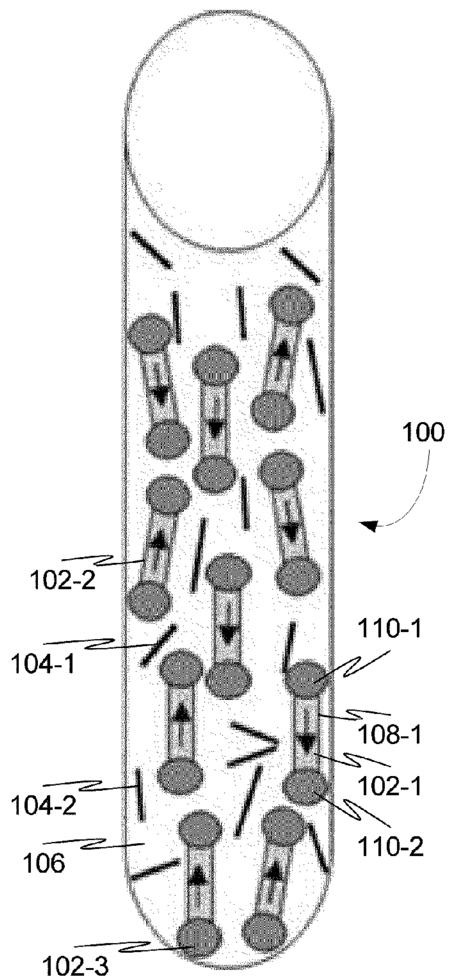
(57) **ABSTRACT**

A reinforcement for buildings is provided. The reinforcement is composed of a mixture of a plurality of piezoelectric rods, a plurality of carbon fibers and cement material. The mixture imparts a vibration damping characteristic in the reinforcement.

19 Claims, 4 Drawing Sheets



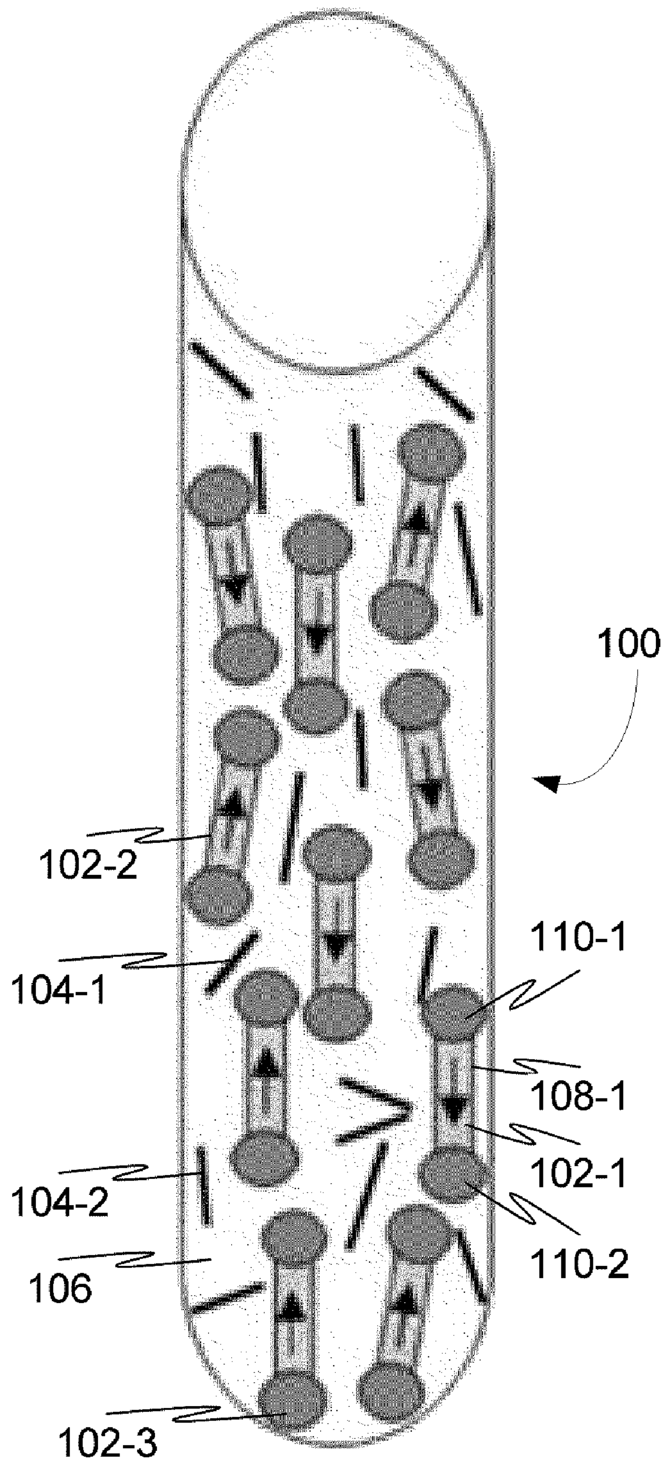


FIG. 1

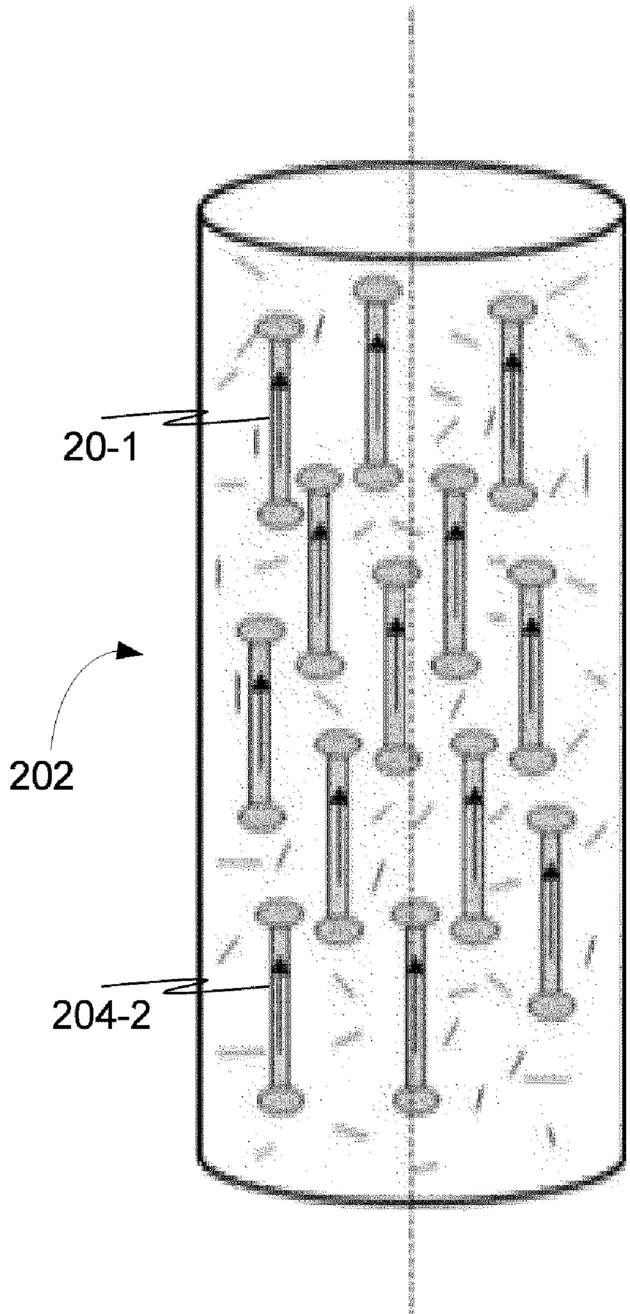


FIG. 2

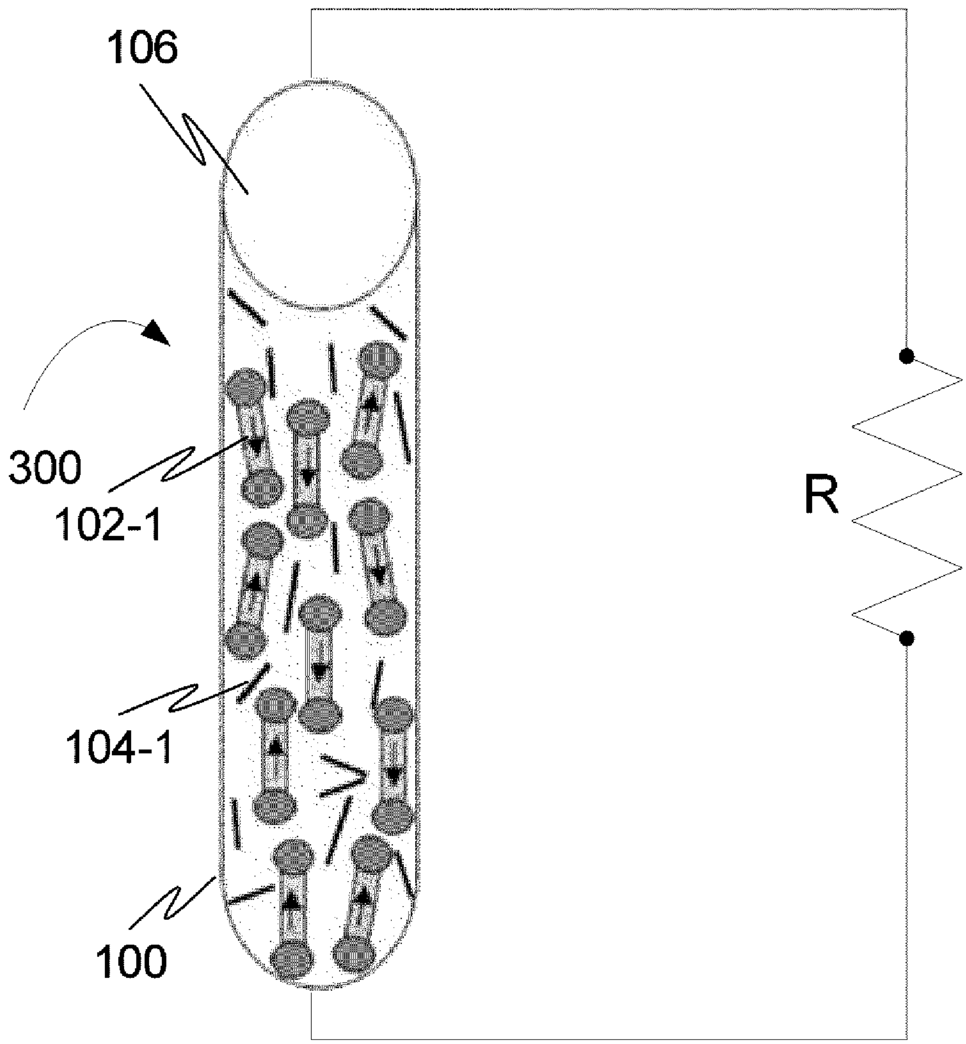


FIG. 3

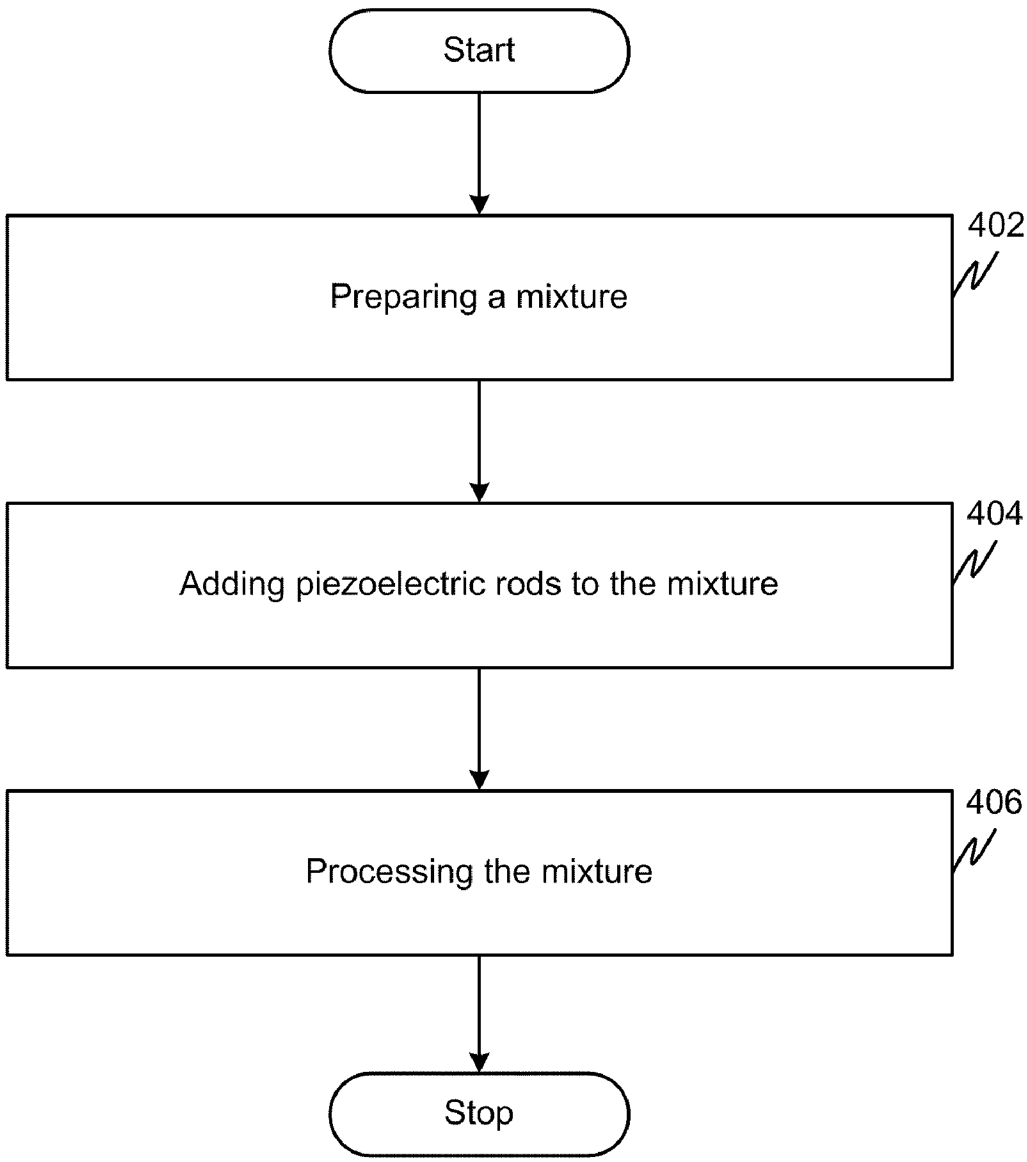

Start
Preparing a mixture
402
Adding piezoelectric rods to the mixture
404
Processing the mixture
406
Stop

FIG. 4

VIBRATION RESISTANT REINFORCEMENT FOR BUILDINGS

FIELD OF THE INVENTION

The invention generally relates to reinforcement used in constructing buildings, and more specifically, to reinforcements having capability of damping vibration in buildings.

BACKGROUND OF THE INVENTION

In civil structures which host sensitive equipments, such as measuring and manufacturing equipments, vibration is considered to be a hazardous phenomenon. Occurrence of minimal vibration in the civil structures may hamper performance of sensitive equipments. Therefore, civil structures such as, buildings corresponding to a fabrication lab or a NANO lab, require minimization of the vibration so that sensitive equipments are not affected.

There have been methods for constructing buildings with civil structure blocks which are vibration resistant. These civil structure blocks are manufactured by embedding viscoelastic polymers in cement material of the civil structure blocks. However, addition of a polymer material in the cement results in inclusion of a softening material. Therefore, overall strength and rigidity of the civil structure blocks is reduced.

In another method, plastic reinforcements are used to provide resistance from corrosion and flexibility in the reinforcements. However, such reinforcements are not vibration resistant.

There is therefore a need of a reinforcement which is capable of damping vibration in buildings. Further, there is a need of maintaining strength and rigidity of such reinforcements.

BRIEF DESCRIPTION OF THE FIGURES

The accompanying figures where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to further illustrate various embodiments and to explain various principles and advantages all in accordance with the invention.

FIG. **1** illustrates a reinforcement in accordance with various embodiments of the invention.

FIG. **2** illustrates orientation of a plurality of piezoelectric rods in a reinforcement in accordance with an embodiment of the invention.

FIG. **3** illustrates a hypothetical electrical circuit for depicting vibration damping characteristic of a reinforcement in accordance with an embodiment of the invention.

FIG. **4** illustrates a flow diagram of manufacturing of a reinforcement in accordance with various embodiments of the invention.

Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Before describing in detail embodiments that are in accordance with the present invention, it should be observed that

the embodiments reside primarily in combinations of method steps and components related to vibration resistant reinforcement for buildings. Accordingly, the components and method steps have been represented where appropriate by conventional symbols in the drawings, showing only those specific details that are pertinent to understanding the embodiments of the invention so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein.

In this document, relational terms such as first and second, top and bottom, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions. The terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. An element proceeded by "comprises . . . a" does not, without more constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises the element.

Generally speaking, pursuant to various embodiments, the invention provides a reinforcement for buildings. The reinforcement includes a mixture of a plurality of piezoelectric rods, a plurality of conductive fibers, and a plastic matrix. The mixture imparts a vibration damping characteristic to the reinforcement.

FIG. **1** illustrates a reinforcement **100** in accordance with various embodiments of the invention. Examples of reinforcement **100** include, but are not limited to a rod, a bar, a wire, a rebar, and a cable. Reinforcement **100** may be used in various civil structures such as, buildings, bridges, tunnels and so forth. Further, a cross-section of reinforcement **100** may be designed into various shapes such as, square, circle, I shape, triangle, and so forth.

Reinforcement **100** is composed of a mixture of a plurality of piezoelectric rods **102**-*n*, a plurality of conductive fibers **104**-*n* and a plastic matrix **106**. The mixture imparts a vibration damping characteristic to reinforcement **100**.

Plurality of piezoelectric rods **102**-*n* may be composed of piezoelectric ceramic materials, such as lead zirconate titanate (PZT) or similar materials. While mixing plurality of piezoelectric rods **102**-*n* in the mixture, plurality of piezoelectric rods **102**-*n* may be oriented in different directions with respect to reinforcement **100**. The orientation of piezoelectric rods **102**-*n* in the mixture is explained in more detail in conjunction with FIG. **2**. Further, plurality of piezoelectric rods **102**-*n* are polarized along longitudinal axis of piezoelectric rods **102**-*n* prior to mixing plurality of piezoelectric rod **102**-*n* to the mixture.

In an embodiment, a piezoelectric rod, such as piezoelectric rod **102-1**, includes a rod **108-1**. Rod **108-1** is composed of a piezoelectric material. Further, piezoelectric rod **102-1** also includes an electrode **110-1** and an electrode **110-2**. Electrode **110-1** and electrode **110-2** are placed at each end of rod **108-1**. In an embodiment, electrode **110**-*n* may be composed of one of a metal material and a piezoelectric material. Further, electrode **110**-*n* may be shaped as an oblate ellipsoid.

In another embodiment, the piezoelectric rod, such as piezoelectric rod **102-1**, is dumbbell shaped, such that ellipsoid ends of the dumbbell shape of the piezoelectric rods act like electrode **110**-*n*. The dumbbell shape enables the piezoelectric rod to efficiently handle and transfer stress which may be developed due to vibration.

Plurality of piezoelectric rods **102**-*n* included in the mixture exhibits piezoelectric property when reinforcement **100** is subjected to stress due to vibration. Based on the stress, plurality of piezoelectric rods **102**-*n* are deformed and mechanical energy of the stress is converted into electrical charge by plurality of piezoelectric rod **102**-*n*.

The electrical charge generated by plurality of piezoelectric rods **102**-*n* is collected at electrodes **110**-*n*. From electrodes **110**-*n*, the electrical charge is passed through the mixture of plurality of conductive fibers **104**-*n* and plastic matrix **106**. In the mixture, a conductive fiber, such as conductive fiber **104-1**, is used for creating an electrical path for transferring electrical charge generated by plurality of piezoelectric rods **102**-*n*. The conductive fiber is composed of a conductive material such as, carbon. The electrical charge passed through the conductive fiber is dissipated as heat energy due to resistance provided by plastic matrix **106**.

Plastic matrix **106** is a binding material for holding plurality of piezoelectric rods **102**-*n* and plurality of conductive fibers **104**-*n* into reinforcement **100**. Plastic matrix **106** is composed of a plastic material such as, thermoplastic, polyethylene, polyvinyl chloride, polypropylene, polystyrene, and acrylonitrile butadiene styrene. Plastic matrix **106** provides resistance from corrosion and flexibility in reinforcement **100**. Further, plastic matrix **106** provides resistance to the electrical charge flowing in plurality of conductive fibers **104**-*n*, which results in dissipation of the electrical charge into heat energy by Joule Effect.

Therefore, the mixture of plurality of piezoelectric rods **102**-*n*, plurality of conductive fibers **104**-*n* and plastic matrix **106** enable dissipation of dynamic stress developed due to vibration in reinforcement **100**, into heat energy. As a result, the mixture imparts a vibration damping characteristic in reinforcement **100**. A level of the vibration damping characteristic is based on a ratio of plurality of piezoelectric rods **102**-*n*, plurality of conductive fibers **104**-*n* and plastic matrix **106** in the mixture. As plurality of piezoelectric rods **102**-*n* directly convert stress developed due to vibration into electrical charge, the level of vibration damping characteristic is directly proportional to a weight percentage of plurality of piezoelectric rods **102**-*n* in the mixture. Thus, a higher weight percentage of plurality of piezoelectric rods **102**-*n* in the mixture imparts higher level of vibration damping characteristic in reinforcement **100**.

Further, the level of vibration damping characteristic is based on a resistance load of reinforcement **100**. The resistance load is resistance created by plastic matrix **106** for dissipating the electrical charge conducted by plurality of conductive fibers **104**-*n*. The resistance load is increased by decreasing a weight percentage of plurality of conductive fibers **104**-*n*. Therefore, the resistance load is inversely proportional to the weight percentage of plurality of conductive fibers **104**-*n*. Further, the resistance load is directly proportional to a weight percentage of plastic matrix **106**. An optimum ratio of weight percentages of plurality of conductive fibers **104**-*n* and plastic matrix **106** is chosen to achieve a required level of resistance load, thereby imparting a required level of vibration damping characteristic in reinforcement **100**. The optimum ratio of the weight percentage of plurality of conductive fibers **104**-*n* depends on a targeted vibration frequency to be absorbed, because increasing or decreasing the weight percentage of plurality of conductive fibers **104**-*n* may affect damping characteristics of reinforcement **100**. Therefore, for the targeted vibration frequency, the weight percentage of plurality of conductive fibers **104**-*n* is maintained as less as possible.

In addition, the level of vibration damping characteristic is also dependent on shape and size of a piezoelectric rod, such as piezoelectric rod **102-1**. An aspect ratio, which is length/radius ratio of the piezoelectric rod, is directly proportional to the level of vibration damping characteristic. A higher aspect ratio results in higher conversion of stress developed due to vibration to electrical charge. Hence, the level of vibration damping characteristic of reinforcement **100** increases. Further, the level of vibration damping characteristic may also be influenced by shape of electrodes **110**-*n* of piezoelectric rod **102-1**. Based on shape of electrodes **110**-*n*, the electrical charge is collected at edges of electrodes **110**-*n* Electrodes of oblate ellipsoid shape can greatly improve the stress transfer efficiency between the piezoelectric rod and the surrounding matrix (plastic **106** and conductive fibers **104**-*n*) due to anchorage effect; thus, enhancing the damping capability of reinforcement **100**, thereby improving stress transfer efficiency in the mixture. Therefore the level of vibration damping characteristic of reinforcement **100** is improved.

Turning now to FIG. **2**, a reinforcement **202** is shown illustrating orientation of a plurality of piezoelectric rods **204**-*n* in accordance with an embodiment of the invention. Plurality of piezoelectric rods **204**-*n* are oriented along a direction parallel to a longitudinal direction of reinforcement **202**. As, reinforcement **202** is generally subjected to tensile stress, the orientation of piezoelectric rods **204**-*n* along the longitudinal direction of reinforcement **202** supports high tensile vibration damping characteristics in reinforcement **202**. In an embodiment of the invention, orientation of plurality of piezoelectric rods **204**-*n* may be along a preferential direction reinforcement **202**. This will enable increasing the vibration damping characteristics along the preferential direction.

FIG. **3** illustrates a hypothetical electrical circuit **300** depicting vibration damping characteristic of reinforcement **100** in accordance with an embodiment of the invention. Hypothetical electrical circuit **300** is formed between plurality of piezoelectric rods **102**-*n*, plurality of conductive fibers **104**-*n* and plastic matrix **106**. In hypothetical electrical circuit **300**, plurality of piezoelectric rods **102**-*n* act like a battery by producing electrical charge, plurality of conductive fibers **104**-*n* provide a conductive path for enabling flow of the electrical charge and plastic matrix **106** provides resistance R in the conductive path.

Hypothetical electrical circuit **300** is activated when reinforcement **100** experiences vibration. Vibration results in application of stress on each piezoelectric rod of plurality of piezoelectric rods **102**-*n*. As the stress is applied on a piezoelectric rod, such as piezoelectric rod **102-1**, shape of the piezoelectric rod is deformed. Deformation of the shape results in generation of electrical charge by piezoelectric rod **102-1**. The electrical charge is gathered at electrodes **110**-*n* and then passed through one or more conductive fibers, such as conductive fiber **104-1**. The one or more conductive fibers may be placed in vicinity of the piezoelectric rod. Further, plastic matrix **106** around the piezoelectric rod and the one or more conductive fibers provides resistance to the electrical charge. Thereafter, the electrical charge is dissipated into heat energy by Joule Effect. As a result, vibration in reinforcement **100** is damped.

Therefore, activation of hypothetical electrical circuit **300** in reinforcement **100** results in imparting a vibration damping characteristic in reinforcement **100**. In an embodiment, hypothetical electrical circuit **300** may be activated between a piezoelectric rod and one or more conductive fibers and plastic matrix **106** around the piezoelectric rod. In another embodiment, hypothetical electrical circuit **300** may be activated between a set of piezoelectric rods and one or more conductive fibers and plastic matrix **106** around the set of piezoelectric rods. Piezoelectric rods in the set of piezoelectric rods are oriented in one direction in such a scenario. Therefore, multiple hypothetical electrical circuits, such as hypothetical electrical circuit **300** may be formed in reinforcement **100**, based on orientation of plurality of piezoelectric rods **102**-*n*. The orientation of plurality of piezoelectric rods **102**-*n*. has been explained in detail in conjunction with FIG. **2**.

FIG. **4** illustrates a flow diagram of manufacturing reinforcement **100** in accordance with various embodiments of the invention. At step **402**, a mixture of plurality of conductive fibers **104**-*n*, and plastic matrix **106** is prepared. Weight percentage of plurality of conductive fibers **104**-*n* in the mixture depends on a required level of vibration damping characteristic of reinforcement **100**. Further, weight percentage of plastic matrix **106** depends on the required level of vibration damping characteristic of reinforcement **100** and required shape and size of reinforcement **100**. In an embodiment, a liquid material, such as a liquid adhesive is also added to the mixture to prepare a paste of the mixture. In another embodiment, plurality of conductive fibers **104**-*n* are added in plastic matrix **106**, which is in a melted state.

Upon preparation of the mixture, plurality of piezoelectric rods **102**-*n* are added to the mixture, at step **404**. Weight percentage of plurality of piezoelectric rods **102**-*n* to be added in the mixture is based on the required level of vibration damping characteristic of reinforcement **100**. While adding plurality of piezoelectric rods **102**-*n* to the mixture, each piezoelectric rod is polarized along a longitudinal direction of the piezoelectric rod.

Thereafter, at step **406**, the mixture is processed to form reinforcement **100**. Various known processing methods may be implemented to accomplish this. For example, processing may involve pouring the mixture in a mould, and drying the mixture.

Various embodiments of the invention provide a reinforcement for buildings which is capable of damping vibration in the buildings. The vibration damping capability is imparted by a mixture of the reinforcement which includes piezoelectric rods, conductive fibers, and plastic matrix. The mixture enables dissipation of mechanical stress developed due to vibration into heat energy. Further, usage of the piezoelectric rods enables maintaining strength and rigidity of the reinforcement. Moreover, as the piezoelectric rods are shaped like a dumbbell, each piezoelectric rod may effectively support the mechanical stress. Therefore, even high frequency of vibration in a building may be damped by the reinforcement. Such reinforcements may be used in the buildings such as, fabrication lab and NANO lab which host sensitive equipments,

Those skilled in the art will realize that the above recognized advantages and other advantages described herein are merely exemplary and are not meant to be a complete rendering of all of the advantages of the various embodiments of the present invention.

In the foregoing specification, specific embodiments of the present invention have been described. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of the present invention. The benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of any or all the claims. The present invention is defined solely by the appended claims including any amendments made during the pendency of this application and all equivalents of those claims as issued.

What is claimed is:

1. A reinforcement for buildings, the reinforcement comprising

a mixture of

a plurality of piezoelectric rods, wherein each piezoelectric rod is dumbbell shaped,

a plurality of conductive fibers, and

a plastic matrix,

whereby the mixture imparts a vibration damping characteristic to the reinforcement.

2. The reinforcement of claim **1**, wherein the reinforcement is rod shaped.

3. The reinforcement of claim **1**, wherein the reinforcement is bar shaped.

4. The reinforcement of claim **1**, wherein the reinforcement is rebar shaped.

5. The reinforcement of claim **1**, wherein a level of the vibration damping characteristic is based on a ratio of the plurality of piezoelectric rods, the plurality of conductive fibers, and the plastic matrix in the mixture.

6. The reinforcement of claim **5**, wherein the level of the vibration damping characteristic is directly proportional to the plurality of piezoelectric rods.

7. The reinforcement of claim **5**, wherein the level of the vibration damping characteristic is directly proportional to a length/radius aspect ratio of a piezoelectric rod.

8. The reinforcement of claim **5**, wherein the ratio of the plurality of piezoelectric rods, the plurality of conductive fibers, and the plastic matrix in the mixture determines an electrical resistance load that is inversely proportional to the plurality of conductive fibers; and

wherein the ratio is selected to include a percentage of the plurality of conductive fibers to achieve an electrical resistance load that targets a specific vibration frequency to be absorbed.

9. The reinforcement of claim **1**, wherein each end of a piezoelectric rod is coupled with an electrode.

10. The reinforcement of claim **9**, wherein the electrode is shaped as an oblate ellipsoid.

11. The reinforcement of claim **9**, wherein the electrode comprises a piezoelectric material.

12. The reinforcement of claim **9**, wherein the electrode comprises a metal material.

13. The reinforcement of claim **9**, wherein a level of the vibration damping characteristic is based on shape of the electrode.

14. The reinforcement of claim **1**, wherein each piezoelectric rod is polarized along a longitudinal axis of the piezoelectric rod.

15. The reinforcement of claim **1**, wherein the plurality of piezoelectric rods are aligned along a preferential direction of the reinforcement.

16. The reinforcement of claim **1**, wherein each piezoelectric rod is aligned parallel to a longitudinal axis of the reinforcement.

17. The reinforcement of claim **1**, wherein each conductive fiber is a carbon fiber.

18. The reinforcement of claim **1**, wherein the plastic matrix comprises at least one of thermoplastic, polyethylene, polyvinyl chloride, polypropylene, polystyrene, and acrylonitrile butadiene styrene.

19. A method for manufacturing a reinforcement for buildings, the method comprising:

preparing a mixture of a plurality of conductive fibers and a plastic matrix;

adding a plurality of piezoelectric rods into the mixture, wherein each piezoelectric rod is dumbbell shaped; and

processing the mixture, upon addition of the plurality of piezoelectric rods into the mixture, to form the reinforcement, whereby a vibration damping characteristic is imparted to the reinforcement.

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