(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 December 2018 (13.12.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/224947 A1

(51) International Patent Classification:
B60R 19/03 (2006.01) *B60R 19/34* (2006.01)
B64C 25/00 (2006.01) *F16F 7/12* (2006.01)

(21) International Application Number:
PCT/IB2018/053990

(22) International Filing Date:
04 June 2018 (04.06.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/515,212 05 June 2017 (05.06.2017) US

(71) Applicant: **SABIC GLOBAL TECHNOLOGIES B.V.** [NL/NL]; Plasticslaan 1, 4612 PX Bergen op Zoom (NL).

(72) Inventors: **BOBBA VENKAT, Somasekhar**; Plot No. 81-85 Village; Chikkadunnasandra, Anekal;, Taluk, Off. Sarjapura-Attibele Rd., Bangalore 562125 (IN). **MILNE, Craig Lawrence**; 2500 City West Blvd., Suite 500, Houston, Texas 77042 (US). **MOHAPATRA, Subhransu Sekhar**; Plot No. 81-85 Village; Chikkadunnasandra, Anekal;, Taluk, Off. Sarjapura-Attibele Rd., Bangalore 562125 (IN). **PETERS, Richard**; 2500 City West Blvd., Suite 500, Houston, Texas 77042 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH,

WO 2018/224947 A1

(54) Title: COMPOSITE CRUSHABLE MEMBER AND METHODS FOR CONTROLLING CRUSHING THEREOF USING REINFORCING COMPOSITES

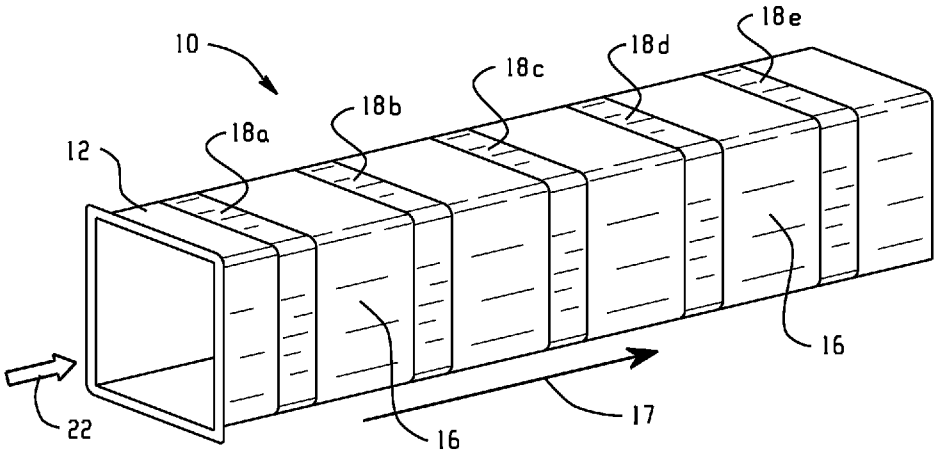


Fig. 1

(57) Abstract: A composite crushable member (10) comprising a reinforcing composite (12) is disclosed herein. The composite crushable member comprises a reinforcing region (16) and a trigger region (18a-18e) and at least one of a first physical property of the trigger region is less than a second physical property of the reinforcing region, wherein the first physical property and second physical property are selected from stiffness, impact strength, tensile strength, compressive strength, and a combination comprising at least one of the foregoing, and a third physical property of the trigger region is greater than a fourth physical property of the reinforcing region, wherein the third physical property and fourth physical property are selected from ductility, malleability, and a combination comprising at least one of the foregoing. The reinforcing composite comprises a reinforcing section corresponding to the reinforcing region and a trigger section corresponding to the trigger region.

[Continued on next page]

GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

COMPOSITE CRUSHABLE MEMBER AND METHODS FOR CONTROLLING CRUSHING THEREOF USING REINFORCING COMPOSITES

BACKGROUND

[0001] Crushable members can be used in a variety of applications in transportation structures to absorb energy or control deformation to help ensure the safety of vehicle occupants during collusions.

[0002] Thus, it would be desirable to provide improved crushable members to help ensure the safety of vehicle occupants.

BRIEF DESCRIPTION

[0003] A composite crushable member can include a reinforcing composite. The reinforcing composite includes at least one of a reinforcing fabric or a unidirectional tape. The at least one reinforcing fabric or unidirectional tape is incorporated into or disposed on a surface of a polymeric substrate. The at least one reinforcing fabric or unidirectional tape includes a plurality of fibers. The composite crushable member includes a reinforcing region and a trigger region and at least one of a first property of the trigger region is less than a second property of the reinforcing region, wherein the first property and second property are selected from stiffness, impact strength, tensile strength, compressive strength, and a combination comprising at least one of the foregoing, and a third property of the trigger region is greater than a fourth property of the reinforcing region, wherein the third property and fourth property are selected from ductility, malleability, and a combination comprising at least one of the foregoing. The reinforcing composite includes a reinforcing section corresponding to the reinforcing region and a trigger section corresponding to the trigger region.

[0004] A transportation structure can include the above-described composite crushable member.

[0005] In another aspect, a method of producing a composite crushable member can include shaping a reinforcing composite to form the composite crushable member. The reinforcing composite includes at least one of a reinforcing fabric or a unidirectional tape. The at least one reinforcing fabric or unidirectional tape is incorporated into or disposed on a surface of a polymeric substrate. The composite crushable member includes a reinforcing region and a trigger region and at least one of a first property of the trigger region is less than a second property of the reinforcing region, wherein the first property and second property are selected from stiffness, impact strength, tensile strength, compressive strength, and a combination

comprising at least one of the foregoing, and a third property of the trigger region is greater than a fourth property of the reinforcing region, wherein the third property and fourth property are selected from ductility, malleability, and a combination comprising at least one of the foregoing. The reinforcing composite includes a reinforcing section corresponding to the reinforcing region and a trigger section corresponding to the trigger region.

[0006] A method of using the above-described composite crushable member can include incorporating the composite crushable member into an energy absorbing region of a transportation structure.

[0007] The above described and other features are exemplified by the following figures, detailed description, claims, and examples.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The following figures are exemplary embodiments wherein the like elements are numbered alike.

[0009] FIG. 1 is an illustration of an embodiment of a composite crushable member.

[0010] FIG. 2 is an illustration of an embodiment of a reinforcing fabric.

[0011] FIGs. 3A-B are illustrations of two embodiments of methods for producing a composite crushable member.

[0012] FIG. 4 is an illustration of a cross-sectional view of a system for infusing a reinforcing fabric with a flowable polymeric material to form a composite crushable member.

[0013] FIG. 5 is an illustration of a composite crushable member as a rail extension attached to a bumper beam and a rail.

[0014] FIG. 6 is an illustration of the test setup of Comparative Example A.

[0015] FIG. 7 is a graphical illustration of force with time results for Comparative Example A.

[0016] FIG. 8 is an illustration of the test setup of Example 1.

[0017] FIG. 9 is a graphical illustration of force with time results for Example 1.

[0018] FIG. 10 is an illustration of the test setup of Example 2.

[0019] FIG. 11 is a graphical illustration of force with time results for Example 2.

[0020] FIG. 12 is an illustration of the test setup of Example 3.

[0021] FIG. 13 is a graphical illustration of force with time results for Example 3.

[0022] FIG. 14 is a graphical illustration of force with displacement results for Comparative Example A and Examples 1-3.

[0023] The above described and other features are exemplified by the following detailed description, claims, and examples.

DETAILED DESCRIPTION

[0024] Disclosed herein are composite crushable members, methods of producing the composite crushable members, and methods for using the composite crushable members in transportation structures. Using methods and composite crushable members described herein, lightweight, reinforced transportation structures can be made with efficient energy absorption and controlled crush behavior during impacts to enhance the safety of the vehicle occupants. The present inventors have designed reinforcing composites which allow for production of crashworthy composite crushable members with strength and stiffness properties comparable to metal crushable members that avoids complicated, costly, or lengthy secondary processing and waste of materials that can be associated with other composite crushable members.

[0025] As used herein, "controlled crush behavior" or "controlled crushing behavior" refers the definition of failure, folding, or crushing of a member or structure in a predefined manner.

[0026] For instance, the weight of metal (e.g., steel or aluminum) required to provide the desired properties (e.g., stiffness, impact strength, tensile strength, compressive strength) in crushable members for particular applications can be undesirable in lightweight, fuel efficient vehicles. Alternatively, unfilled polymer or previous composite crushable members require the use of secondary processes after formation of the members to create triggers that control the crushing behavior of the composites. For example, secondary processes to add perforations or precuts can be used to control, failure, folding, or crushing of the members. As such the present composite crushable members and methods provide a solution to these problems by providing lightweight composite crushable members that do not require secondary processes to provide controlled crushing behavior in the composite crushable members.

[0027] The composite crushable member of the present disclosure includes a reinforcing composite comprising at least one of a reinforcing fabric or a unidirectional tape incorporated into or disposed on a surface of a polymeric substrate. The composite crushable member comprises a reinforcing region and a trigger region. The reinforcing composite comprises a reinforcing section corresponding to the reinforcing region and a trigger section corresponding to the trigger region. The composite crushable member includes at least one of: a first property of the trigger region that is less than a second property of the reinforcing region, wherein the first property and second property are the same property and are at least one of stiffness, tensile

strength, impact strength, compressive strength; a third property of the trigger region that is greater than a fourth property of the reinforcing region, wherein the third property and fourth property are the same property and are at least one of ductility and malleability; or a combination comprising at least one of the foregoing.

[0028] A property of the trigger regions of the composite crushable member selected from stiffness, tensile strength, impact strength, compressive strength, and a combination comprising at least one of the foregoing can be equal to or less than 80%, for example, 20% to 80%, or 30% to 70%, of the same property of the reinforcing regions.

[0029] A property of the trigger regions of the composite crushable member selected from ductility, malleability, and a combination comprising at least one of the foregoing can be equal to or greater than 120%, for example, 120% to 200%, or 130% to 190%, of the same property of the reinforcing regions.

[0030] A reinforcing composite can include a weight ratio of polymer to fiber at the trigger regions greater than a weight ratio of polymer to fiber at the reinforcing regions. The weight ratios of polymer to fiber for each trigger region can be descending along a longitudinal direction of a composite crushable member (e.g., along a length of a tubular composite crushable member). Thus, the weight ratio of polymer to fiber of a first trigger region can be greater than the weight ratio of polymer to fiber of a second trigger region, which can be greater than the weight ratio of polymer to fiber of a third trigger region, which can be greater than the weight ratio of polymer to fiber of a fourth trigger region, which can be greater than the weight ratio of polymer to fiber of a fifth trigger region. Upon application of a compressive force proximate the first trigger region towards the other trigger regions, the first trigger region deforms first or to a greater extent than the subsequent trigger regions. The same applies for the second and subsequent trigger regions, such that the composite crushable member crushes, folds, or fails at one end before or to a greater extent than at the other end.

[0031] The composite crushable member can include a reinforcing composite comprising a plurality of trigger sections, and wherein the trigger sections each comprise different weave patterns, different fiber densities, different fiber orientations, different fiber diameters, different numbers of plies, or a combination comprising at least one of the foregoing.

[0032] The reinforcing composite can be a prepreg. As used herein "prepreg" refers to a material comprising fibers held together by a resin (e.g., rather than by weaving of the fibers). The resin can comprise a thermoplastic or a thermoset. For example, the resin can comprise a thermoset such as an epoxy.

[0033] For instance, the reinforcing composite can comprise a reinforcing fabric prepreg or a unidirectional tape prepreg.

[0034] A reinforcing composite can include a first fiber density of the reinforcing section greater than a second fiber density of the trigger section. For example, a reinforcing composite may comprise a plurality of plies of a reinforcing fabric or a unidirectional tape. A reinforcing section can include a first fiber density greater than a second fiber density due to a greater number of plies of the reinforcing section as compared to the number of plies of the reinforcing fabric in the trigger section. In another example, the fiber density can be reduced in the trigger section relative to the fiber density of the reinforcing section by removal of fibers from a reinforcing fabric (e.g., from a weave) or a unidirectional tape.

[0035] For example, a woven reinforcing fabric can include a first weave pattern of the reinforcing section different from a second weave pattern of the trigger section. For instance, the first weave pattern can be a weave pattern with a closer weave (e.g., a Dutch weave pattern) than the second weave pattern (e.g., a plain weave pattern, a twill weave pattern, or a weave pattern with a higher warp or weft).

[0036] As referred to herein, "plain weave" refers to a weave pattern wherein each warp fiber crosses alternately above and below each weft fiber. As referred to herein, "twill weave" refers to a weave pattern wherein each weft fiber passes alternately over two and under two successive warp fibers, and each warp fiber passes alternately over two and under two successive weft fibers. As referred to herein, "Dutch weave" refers a weave pattern wherein fibers in the warp direction are greater in diameter and/or spaced further apart from one another than fibers in the weft direction. The crimping of weft fibers over and under the warp fibers result in spaces between the weft fibers.

[0037] As used herein, "warp" refers to a longitudinal direction (e.g., a length) of a reinforcing fabric. As used herein, "weft" refers to a direction perpendicular to the warp (e.g., a width) of a reinforcing fabric.

[0038] In an example, a first weave pattern of a reinforcing section can include first fibers, second fibers, third fibers, and fourth fibers, such as: first fibers oriented parallel to a first direction and parallel to each other; second fibers oriented parallel to a second direction, parallel to each other, and at an angle (e.g., an angle between 30° to 150°) to the first fibers; third fibers oriented parallel to a third direction, parallel to each other, at an angle (e.g., an angle between 30° to 150°) to the first fibers, and at an angle (e.g., an angle between 30° to 150°) to the second fibers; and fourth fibers oriented parallel to a fourth direction, parallel to each other, at an angle (e.g., an angle between 30° to 150°) to the first fibers, at an angle (e.g., an angle

between 30° to 150°) to the second fibers, and at an angle (e.g., an angle between 30° to 150°) to the third fibers.

[0039] A second weave pattern of a trigger section can include first fibers, second fibers, and third fibers, such as: first fibers oriented parallel to a first direction and parallel to each other; second fibers oriented parallel to a second direction, parallel to each other, and at an angle (e.g., an angle between 30° to 150°) to the first fibers; and third fibers oriented parallel to a third direction, parallel to each other, at an angle (e.g., an angle between 30° to 150°) to the first fibers, and at an angle (e.g., an angle between 30° to 150°) to the second fibers.

[0040] For instance, the first weave pattern can include first fibers in a longitudinal direction, second fibers at a right angle to the first fibers, third fibers in a diagonal direction to the first fibers and the second fibers, and fourth fibers at a right angle to the third fibers and in a diagonal direction to the first fibers and the second fibers, while the second wave pattern can include first fibers in a longitudinal direction, second fibers at a right angle to the first fibers, and third fibers in a diagonal direction to the first fibers and the second fibers.

[0041] A reinforcing composite can include a minority of fibers in a reinforcing section oriented perpendicular to a dimension, such as a longitudinal dimension, of the composite crushable member into which the reinforcing fabric is incorporated. Desirably, a reinforcing composite can include a majority of fibers in a reinforcing section oriented perpendicular to a dimension, such as a longitudinal dimension, of the composite crushable member such that the majority of fibers are oriented along an anticipated direction of impact (e.g., a direction of anticipated tensile or compression forces). The reinforcing section can have a cross-ply, for instance at a 90-degree angle or 45-degree angle to the direction of the majority of fibers.

[0042] A reinforcing composite can include a majority of fibers of a trigger section oriented perpendicular a dimension, such as a longitudinal dimension, of the composite crushable member into which the reinforcing composite is incorporated.

[0043] As used herein, "fiber density" refers to the mass of the total fibers in a unit of volume of the reinforcing composite. The reinforcing composite can include reinforcing sections with fibers oriented in a different direction than the fibers of a trigger section.

[0044] It should be understood that a reinforcing composite can be designed for any composite crushable member use or application using a simple trial and error method using the description and examples provided herein.

[0045] The reinforcing fabric can be a woven fabric or a nonwoven fabric forming the trigger sections and the reinforcing sections.

[0046] The reinforcing composite can include a plurality of unidirectional tapes. For example, the reinforcing composite can include a plurality of prepreg unidirectional tapes or woven unidirectional tapes forming the trigger sections and the reinforcing sections. For instance, the reinforcing composite can include at least one reinforcing unidirectional tape with a first fiber density greater than a second density of at least one trigger unidirectional tape. The reinforcing composite can include a plurality of unidirectional tapes attached adjacent to one another or a plurality of unidirectional tapes woven together. Each such reinforcing composite can include unidirectional tapes including fiber orientations, fiber density, fiber diameters, a number of plies, or a combination comprising at least one of the foregoing that form a trigger region and a reinforcing region.

[0047] As used herein, "unidirectional tape" refers to a material with equal to or greater than 75 wt.%, for example, equal to or greater than 90 wt.% of fibers in a warp direction or a machine direction of the material. The fibers can be held in a unidirectional position by weaving, stitching, or bonding (e.g., by a resin in a prepreg).

[0048] Unidirectional tapes can provide greater reinforcing capabilities (e.g., stiffness, impact strength, tensile strength or compressive strength) in an anticipated direction of impact as compared to woven fabrics, which include crimped fibers or over-under weaving that can reduce the reinforcing capabilities of the woven fibers.

[0049] When the reinforcing composite is incorporated into a composite crushable member, the reinforcing sections of the reinforcing composite can correspond to reinforcing regions of the composite crushable member. Likewise, the trigger sections of the reinforcing composite can correspond to trigger regions of the composite crushable member. As such, greater deformation at the trigger regions than at the reinforcing regions upon application of a compressive force to a composite crushable member can be controlled by the weave, the fiber density, the orientation of the fibers, the fiber diameters, the number of plies, or a combination comprising at least one the foregoing of the corresponding trigger sections of the reinforcing composite. In other words, the deformation of the composite crushable member can be controlled by the reinforcing composite design.

[0050] The composite crushable member can include a plurality of trigger regions disposed separate from each other along a dimension of the composite crushable member.

[0051] The fibers can be selected from carbon fibers, glass fibers, aramid fibers, polyamide fibers, and a combination comprising at least one of the foregoing. The fibers can be selected from carbon fibers, glass fibers, polyamide fibers, and a combination comprising at

least one of the foregoing. The fibers can comprise aramid fibers. The fibers can comprise polyamide fibers.

[0052] The fibers can be continuous fibers or staple fibers. The fibers can be straight or uncrimped (e.g., devoid of over-under weaving).

[0053] The polymeric substrate can comprise at least one of a thermoplastic and a thermoset.

[0054] As used herein, the term "thermoplastic" refers to a material that is plastic or deformable, melts to a liquid when heated, and freezes to a brittle, glassy state when cooled sufficiently. Examples of thermoplastic polymers include cyclic olefin polymers (e.g., polynorbornenes and copolymers containing norbornenyl units, for example copolymers of a cyclic polymer such as norbornene and an acyclic olefin such as ethylene and propylene), fluoropolymers (e.g., polyvinyl fluoride (PVF), polyvinylidene fluoride (PVDF), fluorinated ethylene-propylene (FEP), polytetrafluoroethylene (PTFE), poly(ethylene-tetrafluoroethylene (PETFE), perfluoroalkoxy (PFA)), polyacetals (e.g., polyoxyethylene and polyoxymethylene), poly(C_{1-6} alkyl)acrylates, polyacrylamides (e.g., unsubstiuted and mono-N- and di-N-(C_{1-8} alkyl)acrylamides), polyacrylonitriles, polyamides (e.g., aliphatic polyamides, polyphthalamides, and polyaramides), polyamideimides, polyanhydrides, polyarylene ethers (e.g., polyphenylene ethers), polyarylene ether ketones (e.g., polyether ether ketones (PEEK) and polyether ketone ketones (PEKK)), polyarylene ketones, polyarylene sulfides (e.g., polyphenylene sulfides (PPS)), polyarylene sulfones (e.g., polyethersulfones (PES), polyphenylene sulfones (PPS)), polybenzothiazoles, polybenzoxazoles, polybenzimidazoles, polycarbonates (e.g., homopolycarbonates and polycarbonate copolymers such as polycarbonate-siloxanes, polycarbonate-esters, and polycarbonate-ester-siloxanes), polyesters (e.g., polyethylene terephthalates, polybutylene terephthalates, polyarylates, and polyester copolymers such as polyester-ethers), polyetherimides (e.g., copolymers such as polyetherimide-siloxane copolymers), polyimides (e.g., copolymers such as polyimide-siloxane copolymers), poly(C_{1-6} alkyl)methacrylates, polymethacrylamides (e.g., unsubstiuted and mono-N- and di-N-(C_{1-8} alkyl)acrylamides), polyolefins (e.g., polyethylenes, such as high density polyethylene (HDPE), low density polyethylene (LDPE), and linear low density polyethylene (LLDPE), polypropylenes, and their halogenated derivatives (such as polytetrafluoroethylenes), and their copolymers, for example ethylene-alpha-olefin copolymers), polyoxadiazoles, polyoxymethylenes, polyphthalides, polysilazanes, polysiloxanes (silicones), polystyrenes (e.g., copolymers such as acrylonitrile-butadiene-styrene (ABS) and methyl methacrylate-butadiene-styrene (MBS)), polysulfides, polysulfonamides, polysulfonates, polysulfones, polythioesters,

polytriazines, polyureas, polyurethanes, vinyl polymers (e.g., polyvinyl alcohols, polyvinyl esters, polyvinyl ethers, polyvinyl halides (e.g., polyvinyl fluoride), polyvinyl ketones, polyvinyl nitriles, polyvinyl thioethers, and polyvinylidene fluorides), or a combination comprising at least one of the foregoing.

[0055] Examples of thermoset materials can include unsaturated polyester, phenolic, epoxy, urethane and vinyl ester resins.

[0056] The reinforcing fabric or the unidirectional tape can be on a surface of a polymeric substrate (e.g., an exterior or interior surface of a shaped polymeric substrate). For instance, a reinforcing fabric or a unidirectional tape can be welded to, adhered to, laminated to, or overmolded with the polymeric substrate (with or without an adhesive). The reinforcing fabric or the unidirectional tape can be incorporated into the polymeric substrate. In an example, the reinforcing fabric or the unidirectional tape can have spaces between the plurality of fibers in which the polymeric substrate is located such that surfaces of the fibers chemically or mechanically interlock with at least a portion of the polymeric substrate. In a reinforcing section of a reinforcing fabric or a unidirectional tape, there can be a lesser amount of total space between the plurality of fibers in which the polymeric substrate is located as compared to an amount of total space between the plurality of fibers in a trigger section of the reinforcing fabric or the unidirectional tape. For example, the reinforcing section can have a total space (X), and the trigger section can have a total space (Y), wherein $X < Y$, for example, $X \leq 0.5Y$ to $0.95Y$.

[0057] The composite crushable member can be a shape selected from tubular, cubic, conic, pyramidal, or a combination comprising at least one of the foregoing. The composite crushable member cross-section can be a polygonal shape with any number of sides (e.g., triangular, rectangular (e.g., square), 5-sided, 6-sided, 7-sided, 8-sided, 9-sided, 10-sided, etc.), circular, or a combination comprising at least one of the foregoing. The composite crushable member can be hollow or solid. Any number or type of reinforcing elements can be attached to or incorporated into the composite crushable member. For instance, a composite crushable member can include reinforcing elements (e.g., in a hollow portion) selected from ribs, legs, gussets, bosses, cells, walls, honeycomb structures, or a combination comprising at least one of the foregoing.

[0058] For example, the composite crushable member can include a reinforcing composite in the shape of a tube. The reinforcing composite can include a reinforcing fabric in the shape of a tube including a hollow core. The tube of reinforcing fabric can include one or more plies of the reinforcing fabric infused with a polymeric substrate to form the reinforcing composite. A closed core insert, such as a solid cylindrical core insert or a solid rectangular core

insert, can be placed in a hollow core of the reinforcing composite to form the composite crushable member. For instance, a closed core insert can be a foam core insert or a polymer core insert.

[0059] The composite crushable member can be a composite sandwich structure. For instance, the composite crushable member can include a reinforcing composite-polymer-reinforcing composite sandwich structure, such as a reinforcing composite-foam-reinforcing composite sandwich structure.

[0060] The composite crushable member can be a tubular shape with a tapered configuration. For instance, the reinforcing composite can include a first portion with a greater number of plies of reinforcing fabric than a second portion with a smaller number of plies of reinforcing fabric, which results in a tapered configuration. At the interface of the first portion and the second portion is a ply drop-off, wherein an incline or taper is present due to the difference in the number of plies in the reinforcing fabric first portion and second portion.

[0061] Cutouts, indentations, member material modifications, component inserts, or other deformation initiators in the polymeric substrate or composite crushable member can be optional or can be absent.

[0062] The composite crushable member can be suitable for electrophoretic painting or any other painting process.

[0063] The composite crushable member can resist, reduce, or eliminate vibration due to road undulations.

[0064] The composite crushable member can meet regulatory requirements (e.g., National Highway Traffic Safety Administration Rules) for occupant crash protection at 56 kilometers per hour for frontal barrier crash tests. The composite crushable member meets regulatory requirements (e.g., National Highway Traffic Safety Administration Rules) for occupant crash protection at 40 kilometers per hour for an offset barrier crash test or for an angled barrier crash test. An exemplary composite crushable member side rail meeting such regulations minimize the intrusion of an impacting object into an occupant area of a passenger vehicle structure and can absorb the energy from an impacting object with a force equal to or less than 160 kiloNewtons (kN), or equal to or less than 150 kiloNewtons, or equal to or less than 100 kiloNewtons.

[0065] The composite crushable member can meet the International Union of Railways (UIC) standards. For instance, the composite crushable member can meet the UIC 566 standard for main longitudinal compression static load equal to or greater than 2,000 kiloNewtons for buffers or automatic couplers, or for diagonal compression load equal to or greater than 500

kiloNewtons applied on two diagonally opposite buffers. An exemplary composite crushable member side rail meeting such regulations can minimize the intrusion of an impacting object into a railway car and can crush along its longitudinal dimension.

[0066] The composite crushable member can have an energy absorption equal to or greater than 1 MegaJoules (MJ) for a vehicle body extremity for each meter of deformation.

[0067] The composite crushable member can be included in a passenger vehicle structure, a manned aircraft structure, an unmanned aerial vehicle structure, a mass transportation structure, an infrastructure component.

[0068] The mass transportation structure can be a train engine structure, a train car structure, or a rapid transit car structure. The composite crushable member can be a mass transportation structure selected from a rail extension, a cab structure, an energy absorber, an anti-climber, a coupler, or a combination comprising at least one of the foregoing. For instance, the composite crushable structure can be an end portion of a passenger train car.

[0069] The passenger vehicle structure can be a car, a motorcycle, a bus, or a truck. The composite crushable member can be passenger vehicle structure selected from an automotive chassis, a crush can, side rails, an underframe, a steering column, or a combination comprising at least one of the foregoing. For instance, the composite crushable member can be configured to be a single component collapsible steering column replacing a multiple component collapsible steering column. The composite crushable member can be adapted to connect to a bummer, a chassis, or a frame of a passenger vehicle.

[0070] The composite crushable member can be an infrastructure component selected from a ground pillar, an off-shore pillar, a crushable rail (e.g., a guard rail), or a combination comprising at least one of the foregoing.

[0071] In an example, the composite crushable member can be used in an automobile as a side rail. The side rail can be attached to a bumper beam and an underframe using plastic overmolds at the front and rear of the side rail. The plastic overmolds can be shaped to conform to the bumper beam and underframe. Molded nuts, which can withstand tensile loads (e.g., towing) as well as torques due to asymmetrical crash, can be used to attach the plastic overmolds to the bumper beam and underframe. The interface between the plastic overmolds and the composite crushable member can be at points where there is ply drop-off (i.e., where the composite is tapered by terminating one or more plies of the reinforcing fabric at particular points on the composite crushable member).

[0072] In another aspect, a method for producing a composite crushable member is provided. The method of producing a composite crushable member includes shaping a reinforcing composite to form the composite crushable member.

[0073] The reinforcing composite can be formed by attaching a reinforcing fabric or a unidirectional tape to a surface of a polymeric substrate (e.g., an exterior or interior surface of a shaped polymeric substrate). For instance, a reinforcing fabric or a unidirectional tape can be welded to, adhered to, laminated to, or overmolded with a polymeric substrate (with or without an adhesive). The reinforcing fabric or a unidirectional tape can be incorporated into a polymeric substrate material while at least a portion of the polymeric substrate material is melted, flowable, in solution, or in the form of a precursor. The polymeric substrate material then can be cooled, heated, cured, cross-linked, or polymerized to form the polymeric substrate. For instance, a melted polymeric substrate material can be impregnated into the reinforcing fabric or unidirectional tape and then cooled to form a reinforcing composite. As used herein "flowable" or "flowing" refers to the ability or act of moving a material in a fluid stream.

[0074] The production of the reinforcing fabric and the combining of the reinforcing fabric with a polymeric substrate can be continuous. For instance, the reinforcing fabric can be continuously woven and combined with the polymeric substrate in-line to form the reinforcing composite.

[0075] Production of the reinforcing fabric can be by weaving a reinforcing fabric with reinforcing sections and trigger sections. For instance, a reinforcing fabric may be woven with reinforcing sections and trigger sections having different weaves, different fiber densities, different fiber orientations, or a combination comprising at least one of the foregoing as to form reinforcing sections and trigger sections. For instance, the trigger sections can include a lower fiber density that the reinforcing sections. Alternatively, a reinforcing fabric may be woven with a uniform weave, uniform fiber density, a uniform fiber orientation, or a combination comprising at least one of the foregoing, and then fibers can be removed at different sections to form reinforcing sections and trigger sections to provide a larger distance or pitch between the remaining fibers in the trigger sections.

[0076] The reinforcing composite can be made by attaching together a plurality of unidirectional tapes and combining the attached unidirectional tapes with (i.e., attaching to or incorporating into) a polymeric substrate to form a reinforcing composite. The unidirectional tapes can comprise a plurality of first unidirectional tapes corresponding to trigger sections and a plurality of second unidirectional tapes corresponding to reinforcing sections. For instance, the

first unidirectional tapes can include a first fiber density greater than a second fiber density of the second prepreg unidirectional tapes.

[0077] In another example, the reinforcing composite can be made by weaving together a plurality of unidirectional tapes having a trigger sections and reinforcing sections. For example, unidirectional tapes including different fiber densities can be woven in the form of a tubular structure around a mandrel. The woven unidirectional tapes can be attached to or incorporated into a polymeric substrate to form a reinforcing composite.

[0078] The combining of the reinforcing fabric or a unidirectional tapes with the polymeric substrate can be by flowing a polymeric material onto the reinforcing fabric or the unidirectional tapes, infusing the reinforcing fabric or the unidirectional tapes with the polymeric material, and solidifying the polymeric material to form the reinforcing composite. The infusing step can be carried out in a vacuum bag. For example, a reinforcing fabric rolled on a foam core can be contacted with a flowable polymeric material in a vacuum bag to infuse the polymeric material into the reinforcing fabric.

[0079] In another example, the infusing can be by contacting a flowable polymeric material onto the interior surface, an exterior surface, or both an interior surface and an exterior surface of a reinforcing fabric with a tubular shape. The infusing of the flowable polymeric material into the reinforcing fabric with a tubular shape can be performed on a tube-in-tube core apparatus, wherein a perforated tube is positioned in the interior of the reinforcing fabric with a tubular shape to apply an outward pressure. A perforated tube-in-tube apparatus is positioned on the exterior of the reinforcing fabric with a tubular shape to apply an inward pressure. Air or another fluid can be circulated through and out of each perforated tube in order to create the outward or inward pressure on the flowable polymeric material on the interior of the reinforcing fabric with a tubular shape.

[0080] In another example, outward pressure can be applied to the interior of a reinforcing fabric with a tubular shape by a collapsible column. The collapsible column is inserted into the interior of a reinforcing fabric with a tubular shape while is in a collapsed configuration. A flowable polymeric material is then flowed onto an interior surface, an exterior surface, or both an interior surface and an exterior surface of a reinforcing fabric with a tubular shape. The collapsible column is then expanded, thus applying outward pressure on the flowable polymeric material to infuse it into the interior surface of the reinforcing fabric.

[0081] The process can optionally comprise forming cutouts, indentations, member material modifications, component inserts, or other deformation initiators in the polymeric substrate, the reinforcing fabric, or composite crushable member. Alternatively, process be

devoid of the formation of cutouts, indentations, member material modifications, component inserts, or other deformation initiators in the polymeric substrate, the reinforcing fabric, or composite crushable member.

[0082] A more complete understanding of the components, processes, and apparatuses disclosed herein can be obtained by reference to the accompanying drawings. These figures (also referred to herein as "FIG.") are merely schematic representations based on convenience and the ease of demonstrating the present disclosure, and are, therefore, not intended to indicate relative size and dimensions of the devices or components thereof and/or to define or limit the scope of the exemplary embodiments. Although specific terms are used in the following description for the sake of clarity, these terms are intended to refer only to the particular structure of the embodiments selected for illustration in the drawings, and are not intended to define or limit the scope of the disclosure. In the drawings and the following description below, it is to be understood that like numeric designations refer to components of like function.

[0083] As illustrated in FIG. 1, composite crushable member 10 can be a transportation structure such as a crushable rail. Composite crushable member 10 can be tubular and include reinforcing composite 12.

[0084] Reinforcing composite 12 can comprise a plurality of unidirectional tapes attached adjacent to one another and disposed on a polymeric substrate. The plurality of unidirectional tapes can be positioned adjacent to one another such that the fiber orientations, fiber density, fiber diameters, a number of plies, or a combination comprising at least one of the foregoing of the unidirectional tapes form trigger regions and reinforcing regions.

[0085] Reinforcing regions 16 are disposed along longitudinal dimension 17 of composite crushable member 10. Trigger regions 18a, 18b, 18c, 18d, 18e are disposed along longitudinal dimension 17 in an alternating pattern between reinforcing regions 16.

[0086] A property of trigger regions 18a, 18b, 18c, 18d, 18e selected from stiffness, tensile strength, impact strength, compressive strength, and a combination comprising at least one of the foregoing can be less than the same property of reinforcing regions 16. A property of trigger regions 18a, 18b, 18c, 18d, 18e selected from ductility, malleability, and a combination comprising at least one the foregoing can be greater than the same property of reinforcing regions 16. As a result, upon application of compressive force 22 on composite crushable member 10 lateral to longitudinal direction 17, trigger regions 18a, 18b, 18c, 18d, 18e deform to a greater extent than or at a time before reinforcing regions 16.

[0087] A property of trigger region 18e selected from stiffness, tensile strength, impact strength, compressive strength and a combination comprising at least one the foregoing can be

greater than the same property of trigger region 18d, which can be greater than the same property of trigger region 18c, which is greater than the same property of trigger region 18b, which is greater than the same property of trigger region 18a. A property of trigger region 18a selected from ductility, malleability, and a combination comprising at least one of the foregoing can be greater than the same property of trigger region 18b, which is greater than the same property of trigger region 18c, which can be greater than the same property of trigger region 18d, which is greater than the same property of trigger region 18e.

[0088] Using an alternating pattern of trigger regions and reinforcing regions, structural crashworthiness via controlled deformation (e.g., failure, folding, or crushing) of composite crushable member 10 can be achieved. Upon application of compressive force 22 on composite crushable member 10 lateral to longitudinal direction 17, trigger region 18a deforms to a greater extent than or at a time before trigger region 18b, which deforms to a greater extent than or at a time before trigger region 18c, which deforms to a greater extent than or at a time before trigger region 18d, which deforms to a greater extent than or at a time before trigger region 18e.

[0089] Thus, the end of composite crushable member 10 that deforms to a greater extent or before the other end of composite crushable member 10 upon application of compressive force 22 can be distal to an occupant area of a transportation vehicle structure including composite crushable member 10 so that occupant safety can be improved.

[0090] FIG. 2 is an illustration of an embodiment of a portion of a reinforcing fabric comprising a plurality of fibers.

[0091] The reinforcing fabric includes reinforcing sections 32 and a trigger section 34 therebetween. As illustrated, reinforcing sections 32 can be of a different weave as compared to the weave of trigger section 34. The fiber density of reinforcing sections 32 can be greater than the fiber density of trigger section 34. When the reinforcing fabric is incorporated into or disposed on a polymeric substrate to form a composite crushable member, reinforcing sections 32 can correspond to reinforcing regions of the composite crushable member. Likewise, trigger section 34 can correspond to a trigger region of the composite crushable member.

[0092] As illustrated in FIG. 3A, method 100 for producing a composite crushable member includes, at 102, combining a reinforcing fabric with a thermoplastic substrate to form a reinforcing composite.

[0093] At 104, the reinforcing composite can be shaped into any desired shape for the composite crushable member, such as a tubular shape. Alternatively, the shaping can be simultaneously with the combining.

[0094] As illustrated in FIG. 3B, method 105 for producing a composite crushable member includes, at 106, forming a reinforcing fabric into the desired shape for the composite crushable member before, at 108, combining the reinforcing fabric with the polymeric substrate to form the composite crushable member comprising a reinforcing fabric. For instance, the reinforcing fabric can be formed into a tubular shape and a melted polymeric substrate material may be impregnated into the tubular reinforcing fabric and then cooled to form a composite crushable member comprising a reinforcing composite that is tubular shaped.

[0095] As illustrated in FIG. 4, the reinforcing composite can be formed by infusing a reinforcing fabric 112 with a polymeric material (e.g., from fibers in the reinforcing fabric (from comingled fibers), and/or from polymeric material 114 located on one or both sides (preferably both sides) of the reinforcing fabric 112). The reinforcing fabric 112 and the polymeric material 114 (e.g., which can be in the form of a sheet or powder) can be located between an inner tube apparatus 116 and an outer tube apparatus 118. The inner tube apparatus (e.g., interior tube-in-tube apparatus) 116 can emit heat; preferably can apply pressure 115 (e.g., radially outward pressure); more preferably, can emit heat and apply pressure 115 (e.g., radially outward pressure). The outer tube apparatus (e.g., exterior tube-in-tube apparatus) 118 can emit heat; preferably can apply pressure 117 (e.g., radially inward pressure); more preferably, can emit heat and apply pressure 117 (e.g., radially inward pressure). In use, the reinforcing fabric 112 is exposed to heat and/or pressure, preferably both heat and pressure. The heat enables the polymeric material to impregnate the reinforcing fabric 112, binding fibers and forming the reinforcing composite. If the polymeric material is a thermoset, the heat and optional pressure allows the polymeric material to flow around individual fibers and cure. If the polymeric material is a thermoplastic, the heat and optional pressure allows the polymeric material to flow around individual fibers. The polymeric material is then allowed to cool and solidify.

[0096] For example, a reinforcing composite can be formed by infusing a reinforcing fabric 112 with a tubular shape with flowable polymeric material 114 using one interior tube-in-tube apparatus 116 and an exterior apparatus (e.g., two, or more, exterior tube-in-tube apparatuses) 118. Inner tube-in-tube apparatus 116 applies outward pressure 115 onto flowable polymeric material 114 and reinforcing fabric 112, while outer tube-in-tube apparatuses 118 apply inward pressure 117 onto flowable polymeric material 114 and reinforcing fabric 112.

[0097] As illustrated in FIG. 5, rail extension 210 is attached at one end to bumper beam 211 by bumper end overmold 212, bolts 214, and molded nuts 216. At its other end, rail extension 210 is attached to rail 219 by overmolds 215 and fasteners 218. At each end of rail

extension 210, ply-drop off joining can be used to join each end to bumper end overmold 212 and rail end overmolds 215.

[0098] This disclosure is further illustrated by the following examples, which are non-limiting.

EXAMPLES

[0099] Computer simulations to test rail extensions were run as follows.

Comparative Example A:

[0100] As illustrated in the test step of FIG. 6, Comparative Example A tested a steel crushable member 40 sandwiched between plate 50 at one end and plate 54 at the other end. Steel crushable member 40 was a tube with an octagon cross-section and a 220 millimeter length. The thickness of the walls of the steel crushable member 40 was 1.7 millimeters. The mass of steel crushable member 40 was 0.9012 kilograms. Steel crushable member 40 had a width of 90 millimeters at the end adjacent to plate 50 and a width of 110 millimeters at the end adjacent to plate 54. Steel crushable member 40 was compressed with compressive force 58 applied by plate 50 having a mass of 1,950 kilograms moving at a velocity of 15 kilometers per hour. The force with time result for Comparative Example A shown in FIG. 7 indicates that steel crushable member was able to achieve a controlled crush behavior such that the force did not exceed 160 KiloNewtons.

Examples 1-3:

[0101] As illustrated in FIG. 8, the test setup for Example 1 was the same as the test setup for Comparative Example A. The same test procedure was used for Example 1 as was used for Comparative Example A. However, instead of steel crushable member 40, composite crushable member 60 was tested. Composite crushable member 60 was a tube with a square-shaped cross-section and a 220 millimeter length. The thickness of the walls of the tube of the composite crushable member 60 was 6 millimeters, with the carbon fiber making up 4 millimeters of the total thickness and polypropylene making up 2 millimeters of the total thickness. The mass of composite crushable member 60 was 0.340 kilograms.

[0102] Composite crushable member 60 included three reinforcing regions and four trigger regions alternating at positions along the longitudinal direction of the composite crushable member 60. The three reinforcing regions were located 25 millimeters from plate 50 (10 millimeters wide), 70 millimeters from plate 50 (10 millimeters wide), and 135 millimeters

from plate 50 (10 millimeters wide). The reinforcing regions were woven with a +45° angle/ -45° angle fiber orientation weave in one ply and a 0° angle/90° angle warp and weft weave in a second ply. The trigger regions were woven with a 0° angle/90° angle warp and weft weave. The resulting force with time for Example 1 shown in FIG. 9 indicates that composite crushable member 60 achieved a comparable controlled crush behavior to Comparative Example A during the initial 50 seconds of the test.

[0103] As illustrated in FIG. 10, the test setup for Example 2 was the same as the test setup for Comparative Example A. The same test procedure was used for Example 2 as was used for Comparative Example A. However, instead of steel crushable member 40, an embodiment of a composite crushable member 70 was tested. The composite crushable member 70 was a polypropylene tube including a woven carbon fiber reinforcing fabric. The composite crushable member 70 was a tube with a square-shaped cross-section and a 220 millimeter length. The thickness of the walls of the composite crushable member 70 was 6 millimeters, with the carbon fiber making up 4 millimeters of the total thickness and polypropylene making up 2 millimeters of the total thickness. The composite crushable member 70 also included two ribs 72 with a thickness of 1.5 millimeters, attached to the interior of the composite crushable member 70. Two ribs 72 attach at the middle of the interior sides the tube of composite crushable member 70, intersecting at the central longitudinal axis of the tube. The mass of composite crushable member 70 was 0.7221 kilograms.

[0104] Composite crushable member 70 included three reinforcing regions and four trigger regions alternating at positions along the longitudinal direction of the composite crushable member 70. The three reinforcing regions were located 25 millimeters from plate 50 (10 millimeters wide), 70 millimeters from plate 50 (10 millimeters wide), and 135 millimeters from plate 50 (10 millimeters wide). The reinforcing regions were woven with a +45° angle/ -45° angle fiber orientation weave in one ply and a 0° angle/90° angle warp and weft weave in a second ply. The trigger regions were woven with a 0° angle/90° angle warp and weft weave. The resulting force with time for Example 2 shown in FIG. 11 indicates a similar controlled crush behavior was achieved by Example 2 as compared to Comparative Example A, but yet composite crushable member 70 had a lower mass than Comparable Example A.

[0105] As illustrated in FIG. 12, the test setup for Example 3 was the same as the test setup for Comparative Example A. The same test procedure was used for Example 3 as was used for Comparative Example A. However, instead of steel crushable member 40, an embodiment of a composite crushable member 80 was tested. The composite crushable member 80 was a polypropylene tube including a woven carbon fiber reinforcing fabric. The composite

member 80 was a tube with a square-shaped cross-section and a 220 millimeter length. The thickness of the walls of the composite crushable member 80 was 6 millimeters, with the carbon fiber making up 4 millimeters of the total thickness and polypropylene making up 2 millimeters of the total thickness. The composite crushable member 80 also included honeycombs 82 with a wall thickness of 1 millimeter, attached to the interior of the composite crushable member 80. The mass of composite crushable member was 0.7221 kilograms.

[0106] Composite crushable member 80 included three reinforcing regions and four trigger regions alternating at positions along the longitudinal direction of the composite crushable member 80. The three reinforcing regions were located 25 millimeters from plate 50 (10 millimeters wide), 70 millimeters from plate 50 (10 millimeters wide), and 135 millimeters from plate 50 (10 millimeters wide). The reinforcing regions were woven with a +45° angle/ -45° angle fiber orientation weave in one ply and a 0° angle/90° angle warp and weft weave in a second ply. The trigger regions were woven with a 0° angle/90° angle warp and weft weave only. The resulting force with time for Example 3 shown in FIG. 13 indicates a similar response was achieved by Example 3 as compared to Comparative Example A.

[0107] As shown in FIG. 14, Examples 2-3 did not result in a force exceeding 160 KiloNewtons with displacement of the composite crushable member along its length, which was comparable to the resulting forces in Comparative Example A.

[0108] Thus, the methods and composite crushable members described herein provide lightweight, reinforcement for transportation structures with controlled crush behavior during impacts comparable to the crush behaviors of metal crushable members. Advantageously, the reinforcing composites can be formed in a single stage to provide reinforcing regions and trigger regions in the composite crushable members without the use of secondary processes to create trigger regions.

[0109] This disclosure further encompasses the following aspects.

[0110] Aspect 1. A composite crushable member comprising: a reinforcing composite comprising at least one of a reinforcing fabric or a unidirectional tape incorporated into or disposed on a surface of a polymeric substrate, the at least one reinforcing fabric or unidirectional tape comprising a plurality of fibers, wherein the composite crushable member comprises a reinforcing region and a trigger region, and wherein the reinforcing composite comprises a reinforcing section corresponding to the reinforcing region and a trigger section corresponding to the trigger region, and wherein at least one of: a first property of the trigger region is less than a second property of the reinforcing region, wherein the first property and second property are selected from stiffness, impact strength, tensile strength, compressive

strength, and a combination comprising at least one of the foregoing, and a third property of the trigger region is greater than a fourth property of the reinforcing region, wherein the third property and fourth property are selected from ductility, malleability, and a combination comprising at least one of the foregoing.

[0111] Aspect 2. The composite crushable member of Aspect 1, wherein at least one of: the first property is equal to or less than 80% of the second property, and the third property is equal to or greater than 120% of the fourth property.

[0112] Aspect 3. The composite crushable member of any one or more of the preceding aspects, wherein the reinforcing composite comprises at least one of: a first weave pattern of the reinforcing section different from a second weave pattern of the trigger section, a first fiber density of the reinforcing section greater than a second fiber density of the trigger section, a first fiber diameter of the reinforcing section greater than a second fiber diameter of the trigger section, a minority of fibers in the reinforcing section oriented perpendicular to a longitudinal dimension of the composite crushable member, and a majority of fibers in the trigger section oriented perpendicular to a longitudinal dimension of the composite crushable member.

[0113] Aspect 4. The composite crushable member of any one or more of the preceding aspects, wherein a first weight ratio of polymer to fiber of the trigger region is greater than a second weight ratio of polymer to fiber of the reinforcing region.

[0114] Aspect 5. The composite crushable member of any one or more of the preceding aspects, further comprising a reinforcing element selected from ribs, legs, gussets, bosses, cells, walls, honeycomb structures, or a combination comprising at least one of the foregoing .

[0115] Aspect 6. The composite crushable member of any one or more of the preceding aspects, wherein the composite crushable member comprises a plurality of trigger regions disposed separate from each other along a dimension of the composite crushable member.

[0116] Aspect 7. The composite crushable member of any one or more of the preceding aspects, wherein the reinforcing composite comprises a plurality of trigger sections, and wherein the trigger sections each comprise different weave patterns, different fiber densities, different fiber orientations, different fiber diameters, or a combination comprising at least one of the foregoing.

[0117] Aspect 8. The composite crushable member of any one or more of the preceding aspects, wherein the reinforcing composite comprises a plurality of adjacent or woven unidirectional tapes.

[0118] Aspect 9. The composite crushable member of any one or more of the preceding aspects, wherein the fibers are selected from carbon fibers, glass fibers, polyamide fibers, aramid

fibers and a combination comprising at least one of the foregoing; preferably selected from carbon fibers, glass fibers, polyamide fibers, aramid fibers and a combination comprising at least one of the foregoing; or comprising aramid.

[0119] Aspect 10. The composite crushable member of any one or more of the preceding aspects, wherein the polymeric substrate comprises a polyacetal, poly(C_{1-6} alkyl)acrylate, polyacrylamide, polyacrylonitrile, polyamide, polyamideimide, polyanhydride, polyarylene ether, polyarylene ether ketones, polyarylene ketone, polyarylene sulfide, polyarylene sulfone, polybenzothiazole, polybenzoxazole, polybenzimidazole, polycarbonate, polyester, polyetherimide, polyimide, poly(C_{1-6} alkyl)methacrylate, polymethacrylamide, cyclic olefin polymer, polyolefin, polyoxadiazole, polyoxymethylene, polyphthalide, polysilazane, polysiloxane, polystyrene, polysulfide, polysulfonamide, polysulfonate, polythioester, polytriazine, polyurea, polyurethane, vinyl polymer, or a combination comprising at least one of the foregoing.

[0120] Aspect 11. The composite crushable member of any one or more of the preceding aspects, comprising a shape selected from tubular, cubic, conic, pyramidal, or a combination comprising at least one of the foregoing.

[0121] Aspect 12. A transportation structure comprising the composite crushable member of any one or more of the preceding aspects.

[0122] Aspect 13. The transportation structure of Aspect 12, comprising a passenger vehicle structure, a manned aircraft structure, an unmanned aerial vehicle structure, a mass transportation structure, or an infrastructure component.

[0123] Aspect 14. A method of producing a composite crushable member comprising: shaping a reinforcing composite to form the composite crushable member comprising a reinforcing region and a trigger region, the reinforcing composite comprising at least one of a reinforcing fabric or a unidirectional tape incorporated into a polymeric substrate or disposed on a surface of the polymeric substrate, and the at least one reinforcing fabric or unidirectional tape comprising a plurality of fibers, wherein the reinforcing composite comprises a reinforcing section corresponding to the reinforcing region and a trigger section corresponding to the trigger region, and wherein at least one of: a first property of the trigger region is less than a second property of the reinforcing region, wherein the first property and second property are selected from stiffness, impact strength, tensile strength, compressive strength, and a combination comprising at least one of the foregoing, and a third property of the trigger region is greater than a fourth property of the reinforcing region, wherein the third property and fourth property are selected from ductility, malleability, and a combination comprising at least one of the foregoing.

[0124] Aspect 15. The method of Aspect 14, wherein the reinforcing composite comprises at least one of: a first weave pattern of the reinforcing section different from a second weave pattern of the trigger section, a first fiber density of the reinforcing section greater than a second fiber density of the trigger section, a first fiber diameter of the reinforcing section greater than a second fiber diameter of the trigger section, a minority of fibers in the reinforcing section oriented perpendicular to a longitudinal dimension of the composite crushable member, and a majority of fibers in the trigger section oriented perpendicular to a longitudinal dimension of the composite crushable member.

[0125] Aspect 16. The method of any one or more of Aspects 14 to 15, further comprising combining the at least one reinforcing fabric or unidirectional tape with a flowable polymeric substrate material to form the reinforcing composite.

[0126] Aspect 17. The method of any one or more of Aspects 14 to 16, wherein the reinforcing composite is shaped into a shape selected from tubular, cubic, conic, pyramidal, or a combination comprising at least one of the foregoing.

[0127] Aspect 18. The method of any one or more of Aspects 14 to 17, further comprising weaving the reinforcing fabric from fibers, weaving the unidirectional tapes, or weaving both fibers and unidirectional tapes.

[0128] Aspect 19. The method of any one or more of Aspects 14 to 18, wherein the at least one of a reinforcing fabric or a unidirectional tape is incorporated into the polymeric substrate by overmolding the at least one of a reinforcing fabric or a unidirectional tape.

[0129] Aspect 20. The method of any one or more of Aspects 14 to 19, comprising welding the at least one of a reinforcing fabric or a unidirectional tape is to the surface of the polymeric substrate.

[0130] Aspect 21. The method of any one or more of Aspects 14 to 20, comprising attaching the at least one of a reinforcing fabric or a unidirectional tape is to the surface of the polymeric substrate with an adhesive.

[0131] Aspect 22. The method of any one or more of Aspects 14 to 21, comprising laminating the at least one of a reinforcing fabric or a unidirectional tape is to the surface of the polymeric substrate.

[0132] Aspect 23. A method of using the composite crushable member of any one or more of Aspects 1 to 11, comprising: incorporating the composite crushable member into an energy absorbing region of a transportation structure.

[0133] Aspect 24. The method of Aspect 19, wherein the incorporating comprises replacing a metal crushable member with the composite crushable member.

[0134] Aspect 25. The method, transportation member, or the composite crushable member of any one or more of the preceding Aspects, wherein the first property and second property comprise stiffness.

[0135] Aspect 26. The method, transportation member, or the composite crushable member of any one or more of the preceding Aspects, wherein the first property and second property comprise impact strength.

[0136] Aspect 27. The method, transportation member, or the composite crushable member of any one or more of the preceding Aspects, wherein the first property and second property comprise tensile strength.

[0137] Aspect 28. The method, transportation member, or the composite crushable member of any one or more of the preceding Aspects, wherein the first property and second property comprise compressive strength

[0138] Aspect 29. The method, transportation member, or the composite crushable member of any one or more of the preceding Aspects, wherein the third property and fourth property comprise ductility.

[0139] Aspect 30. The method, transportation member, or the composite crushable member of any one or more of the preceding Aspects, wherein the third property and fourth property comprise malleability.

[0140] Aspect 31. A method of producing a composite crushable member of any of Aspects 1 – 13, comprising: disposing the at least one of a reinforcing fabric or a unidirectional tape between an inner tube apparatus and an outer tube apparatus; disposing a polymeric material between the inner tube apparatus and/or the outer tube apparatus, preferably both the inner tube apparatus and the outer tube apparatus, and the at least one of a reinforcing fabric or a unidirectional tape; applying at least one of heat or pressure, preferably applying both heat and pressure, on the polymeric material from at least one of the inner tube apparatus or the outer tube apparatus; and impregnating the at least one of a reinforcing fabric or a unidirectional tape with the polymeric material to form the reinforcing composite.

[0141] Aspect 32. The method of Aspect 31, wherein the inner tube apparatus applies outward pressure onto the polymeric material located between the reinforcing fabric and the inner tube apparatus, while the outer tube apparatus applies inward pressure onto the polymeric material located between the reinforcing fabric and the outer tube apparatus.

[0142] The compositions, methods, and articles can alternatively comprise, consist of, or consist essentially of, any appropriate components or steps herein disclosed. The compositions, methods, and articles can additionally, or alternatively, be formulated so as to be devoid, or

substantially free, of any steps, components, materials, ingredients, adjuvants, or species that are otherwise not necessary to the achievement of the function or objectives of the compositions, methods, and articles.

[0143] Unless otherwise specified herein, any reference to standards, regulations, testing methods and the like refers to the most recent standard, regulation, guidance or method that is in force on June 5, 2017.

[0144] The singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. "Or" means "and/or" unless clearly indicated otherwise by context. The terms "first," "second," and the like, "primary," "secondary," and the like, as used herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another.

[0145] The endpoints of all ranges directed to the same component or property are inclusive and independently combinable (e.g., ranges of "less than or equal to 25 wt%, or 5 wt% to 20 wt%," is inclusive of the endpoints and all intermediate values of the ranges of "5 wt% to 25 wt%," etc.). Disclosure of a narrower range or more specific group in addition to a broader range is not a disclaimer of the broader range or larger group.

[0146] The suffix "(s)" is intended to include both the singular and the plural of the term that it modifies, thereby including at least one of that term (e.g., the colorant(s) includes at least one colorants). "Optional" or "optionally" means that the subsequently described event or circumstance can or cannot occur, and that the description includes instances where the event occurs and instances where it does not. Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of skill in the art to which this disclosure belongs. A "combination" is inclusive of blends, mixtures, alloys, reaction products, and the like.

[0147] While typical embodiments have been set forth for the purpose of illustration, the foregoing descriptions should not be deemed to be a limitation on the scope herein. Accordingly, various modifications, adaptations, and alternatives can occur to one skilled in the art without departing from the spirit and scope herein.

CLAIMS

1. A composite crushable member comprising:

a reinforcing composite comprising at least one of a reinforcing fabric or a unidirectional tape incorporated into or disposed on a surface of a polymeric substrate, the at least one reinforcing fabric or unidirectional tape comprising a plurality of fibers,

wherein the composite crushable member comprises a reinforcing region and a trigger region, and

wherein the reinforcing composite comprises a reinforcing section corresponding to the reinforcing region and a trigger section corresponding to the trigger region, and

wherein at least one of,

a first property of the trigger region is less than a second property of the reinforcing region, wherein the first property and second property are selected from stiffness, impact strength, tensile strength, compressive strength, and a combination comprising at least one of the foregoing, and

a third property of the trigger region is greater than a fourth property of the reinforcing region, wherein the third property and fourth property are selected from ductility, malleability, and a combination comprising at least one of the foregoing.

2. The composite crushable member of Claim 1, wherein at least one of

the first property is equal to or less than 80% of the second property, and

the third property is equal to or greater than 120% of the fourth property.

3. The composite crushable member of any one or more of the preceding claims, wherein the reinforcing composite comprises at least one of,

a first weave pattern of the reinforcing section different from a second weave pattern of the trigger section,

a first fiber density of the reinforcing section greater than a second fiber density of the trigger section,

a first fiber diameter of the reinforcing section greater than a second fiber diameter of the trigger section,

a minority of fibers in the reinforcing section oriented perpendicular to a longitudinal dimension of the composite crushable member, and

a majority of fibers in the trigger section oriented perpendicular to a longitudinal dimension of the composite crushable member.

4. The composite crushable member of any one or more of the preceding claims, wherein a first weight ratio of polymer to fiber of the trigger region is greater than a second weight ratio of polymer to fiber of the reinforcing region.

5. The composite crushable member of any one or more of the preceding claims, further comprising a reinforcing element selected from ribs, legs, gussets, bosses, cells, walls, honeycomb structures, or a combination comprising at least one of the foregoing .

6. The composite crushable member of any one or more of the preceding claims, wherein the composite crushable member comprises a plurality of trigger regions disposed separate from each other along a dimension of the composite crushable member.

7. The composite crushable member of any one or more of the preceding claims, wherein the reinforcing composite comprises a plurality of trigger sections, and wherein the trigger sections each comprise different weave patterns, different fiber densities, different fiber orientations, different fiber diameters, or a combination comprising at least one of the foregoing.

8. The composite crushable member of any one or more of the preceding claims, wherein the reinforcing composite comprises a plurality of adjacent or woven unidirectional tapes.

9. The composite crushable member of any one or more of the preceding claims, wherein the fibers are selected from carbon fibers, glass fibers, polyamide fibers, aramid fibers and a combination comprising at least one of the foregoing; preferably selected from carbon fibers, glass fibers, polyamide fibers, aramid fibers and a combination comprising at least one of the foregoing; or comprising aramid.

10. The composite crushable member of any one or more of the preceding claims, wherein the polymeric substrate comprises a polyacetal, poly(C_{1-6} alkyl)acrylate, polyacrylamide, polyacrylonitrile, polyamide, polyamideimide, polyanhydride, polyarylene ether, polyarylene ether ketones, polyarylene ketone, polyarylene sulfide, polyarylene sulfone, polybenzothiazole, polybenzoxazole, polybenzimidazole, polycarbonate, polyester, polyetherimide, polyimide, poly(C_{1-6} alkyl)methacrylate, polymethacrylamide, cyclic olefin polymer, polyolefin, polyoxadiazole, polyoxymethylene, polyphthalide, polysilazane, polysiloxane, polystyrene, polysulfide, polysulfonamide, polysulfonate, polythioester, polytriazine, polyurea, polyurethane, vinyl polymer, or a combination comprising at least one of the foregoing.

11. The composite crushable member of any one or more of the preceding claims, comprising a shape selected from tubular, cubic, conic, pyramidal, or a combination comprising at least one of the foregoing.

12. A transportation structure comprising the composite crushable member of any one or more of the preceding claims; preferably the transportation structure comprises a passenger vehicle structure, a manned aircraft structure, an unmanned aerial vehicle structure, a mass transportation structure, or an infrastructure component.

13. A method of producing a composite crushable member comprising:

shaping a reinforcing composite to form the composite crushable member comprising a reinforcing region and a trigger region, the reinforcing composite comprising at least one of a reinforcing fabric or a unidirectional tape incorporated into a polymeric substrate or disposed on a surface of the polymeric substrate, and the at least one reinforcing fabric or unidirectional tape comprising a plurality of fibers,

wherein the reinforcing composite comprises a reinforcing section corresponding to the reinforcing region and a trigger section corresponding to the trigger region, and

wherein at least one of

a first property of the trigger region is less than a second property of the reinforcing region, wherein the first property and second property are selected from stiffness, impact strength, tensile strength, compressive strength, and a combination comprising at least one of the foregoing, and

a third property of the trigger region is greater than a fourth property of the reinforcing region, wherein the third property and fourth property are selected from ductility, malleability, and a combination comprising at least one of the foregoing.

14. The method of Claim 13, wherein the reinforcing composite comprises at least one of

a first weave pattern of the reinforcing section different from a second weave pattern of the trigger section,

a first fiber density of the reinforcing section greater than a second fiber density of the trigger section,

a first fiber diameter of the reinforcing section greater than a second fiber diameter of the trigger section,

a minority of fibers in the reinforcing section oriented perpendicular to a longitudinal dimension of the composite crushable member, and

a majority of fibers in the trigger section oriented perpendicular to a longitudinal dimension of the composite crushable member.

15. The method of any one or more of Claims 13 to 14, further comprising combining the at least one reinforcing fabric or unidirectional tape with a flowable polymeric substrate material to form the reinforcing composite.

16. The method of any one or more of Claims 13 to 15, wherein the reinforcing composite is shaped into a shape selected from tubular, cubic, conic, pyramidal, or a combination comprising at least one of the foregoing.

17. The method of any one or more of Claims 13 to 16, further comprising weaving the reinforcing fabric from fibers, weaving the unidirectional tapes, or weaving both fibers and unidirectional tapes.

18. A method of using the composite crushable member of any one or more of Claims 1 to 11, comprising:

incorporating the composite crushable member into an energy absorbing region of a transportation structure.

19. The method of Claim 18, wherein the incorporating comprises replacing a metal crushable member with the composite crushable member.

20. A method of producing a composite crushable member of any of Claims 1 – 13, comprising:

disposing the at least one of a reinforcing fabric or a unidirectional tape between an inner tube apparatus and an outer tube apparatus;

disposing a polymeric material between the inner tube apparatus and/or the outer tube apparatus, preferably both the inner tube apparatus and the outer tube apparatus, and the at least one of a reinforcing fabric or a unidirectional tape;

applying at least one of heat or pressure, preferably applying both heat and pressure, on the polymeric material from at least one of the inner tube apparatus or the outer tube apparatus; and

impregnating the at least one of a reinforcing fabric or a unidirectional tape with the polymeric material to form the reinforcing composite.

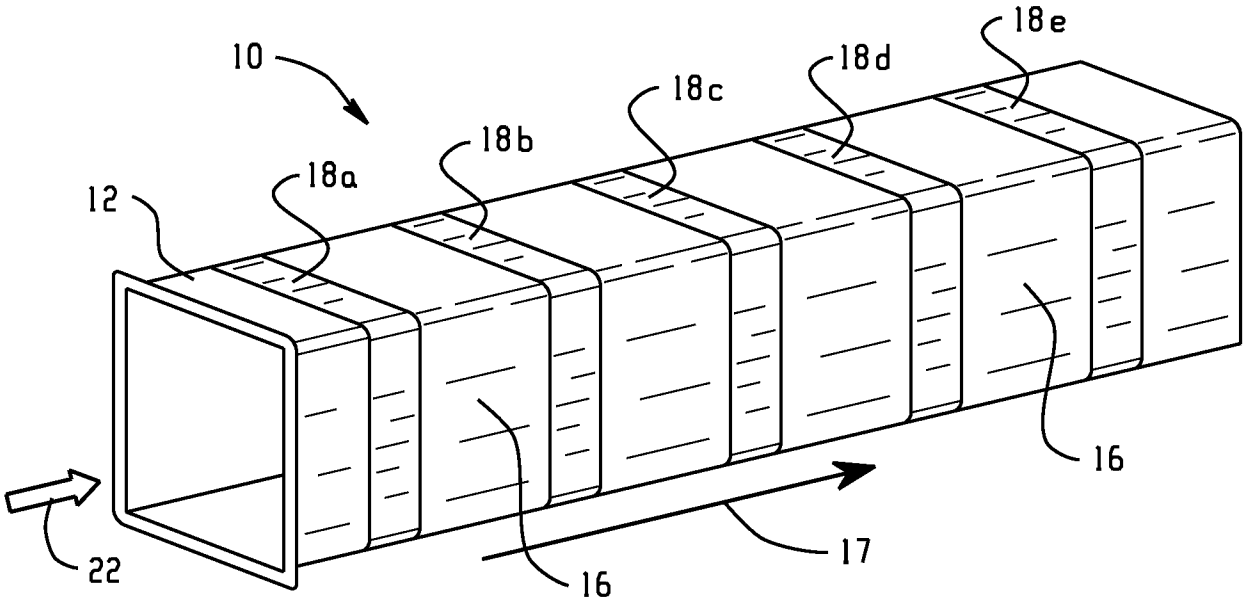


Fig. 1

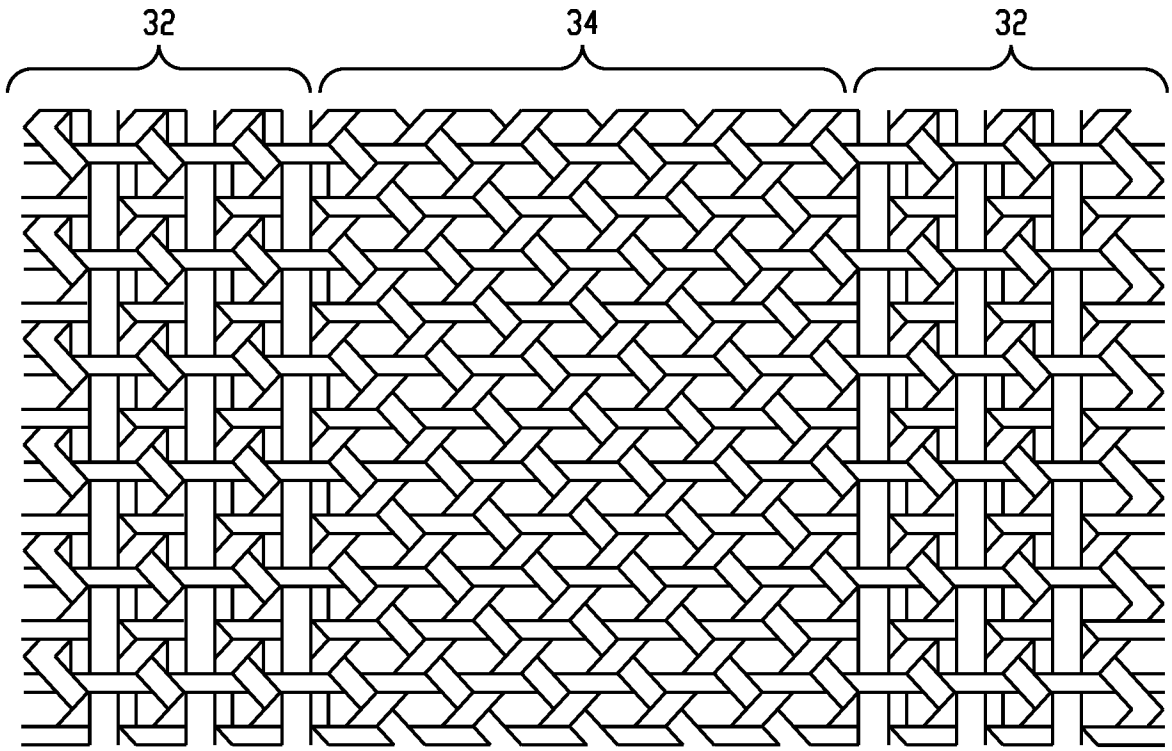


Fig. 2

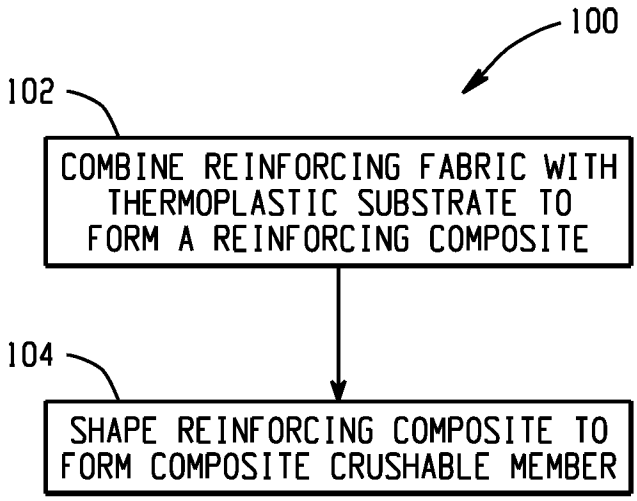

100
102
COMBINE REINFORCING FABRIC WITH THERMOPLASTIC SUBSTRATE TO FORM A REINFORCING COMPOSITE
104
SHAPE REINFORCING COMPOSITE TO FORM COMPOSITE CRUSHABLE MEMBER

Fig. 3A

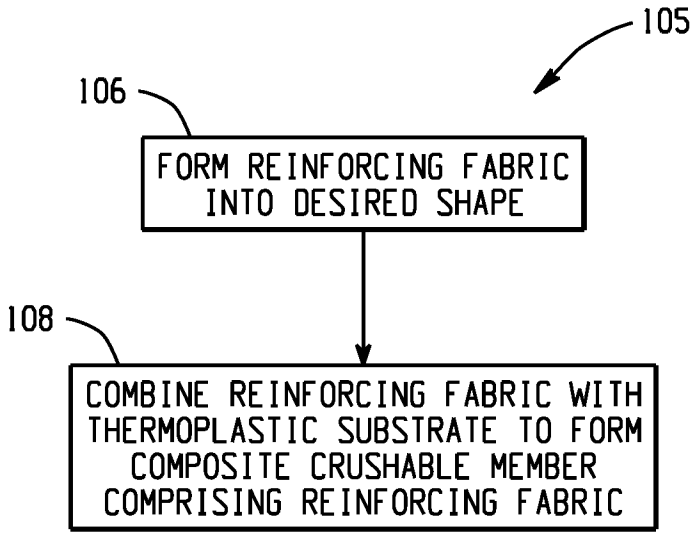

105
106
FORM REINFORCING FABRIC INTO DESIRED SHAPE
108
COMBINE REINFORCING FABRIC WITH THERMOPLASTIC SUBSTRATE TO FORM COMPOSITE CRUSHABLE MEMBER COMPRISING REINFORCING FABRIC

Fig. 3B

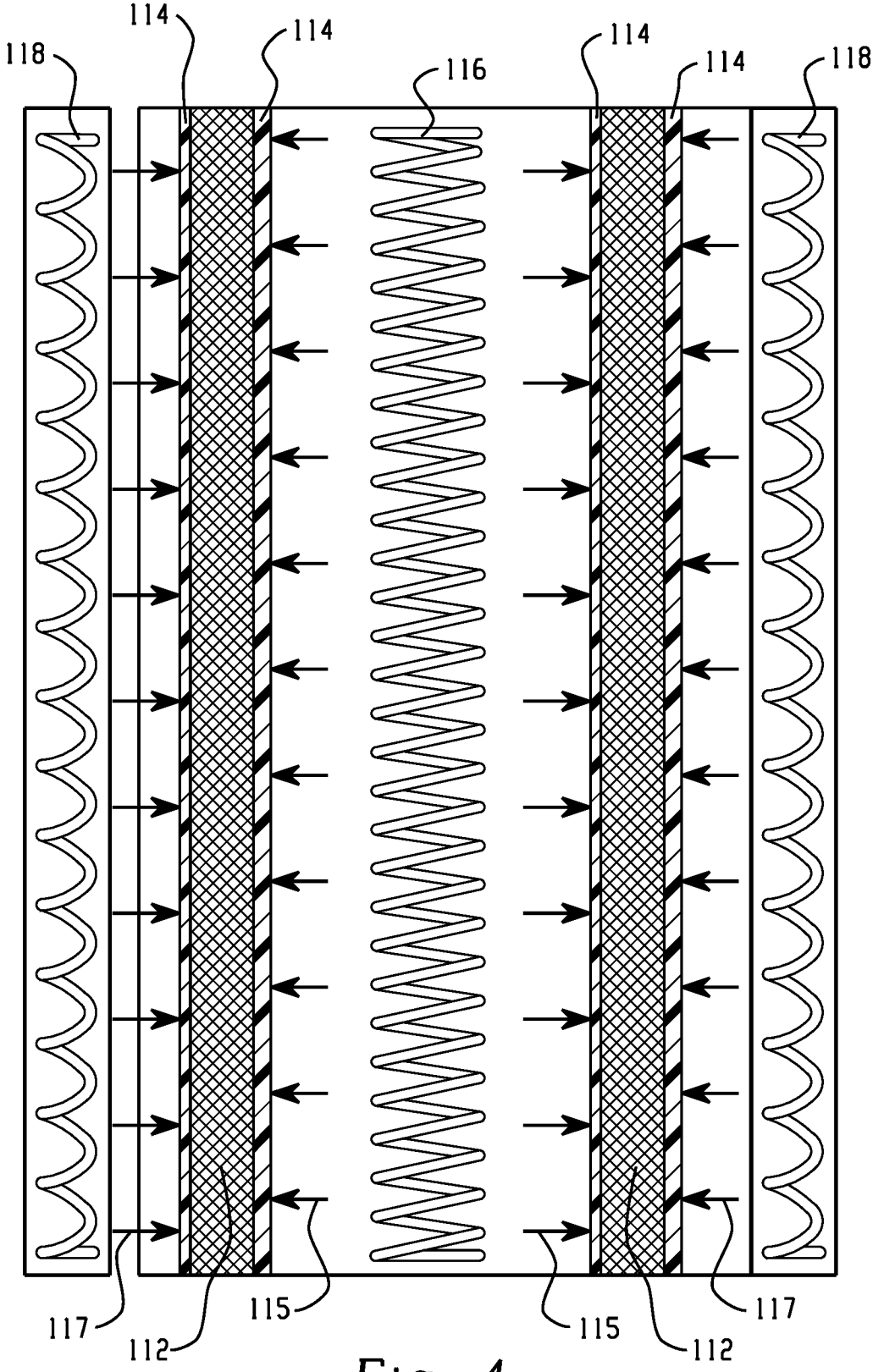


Fig. 4

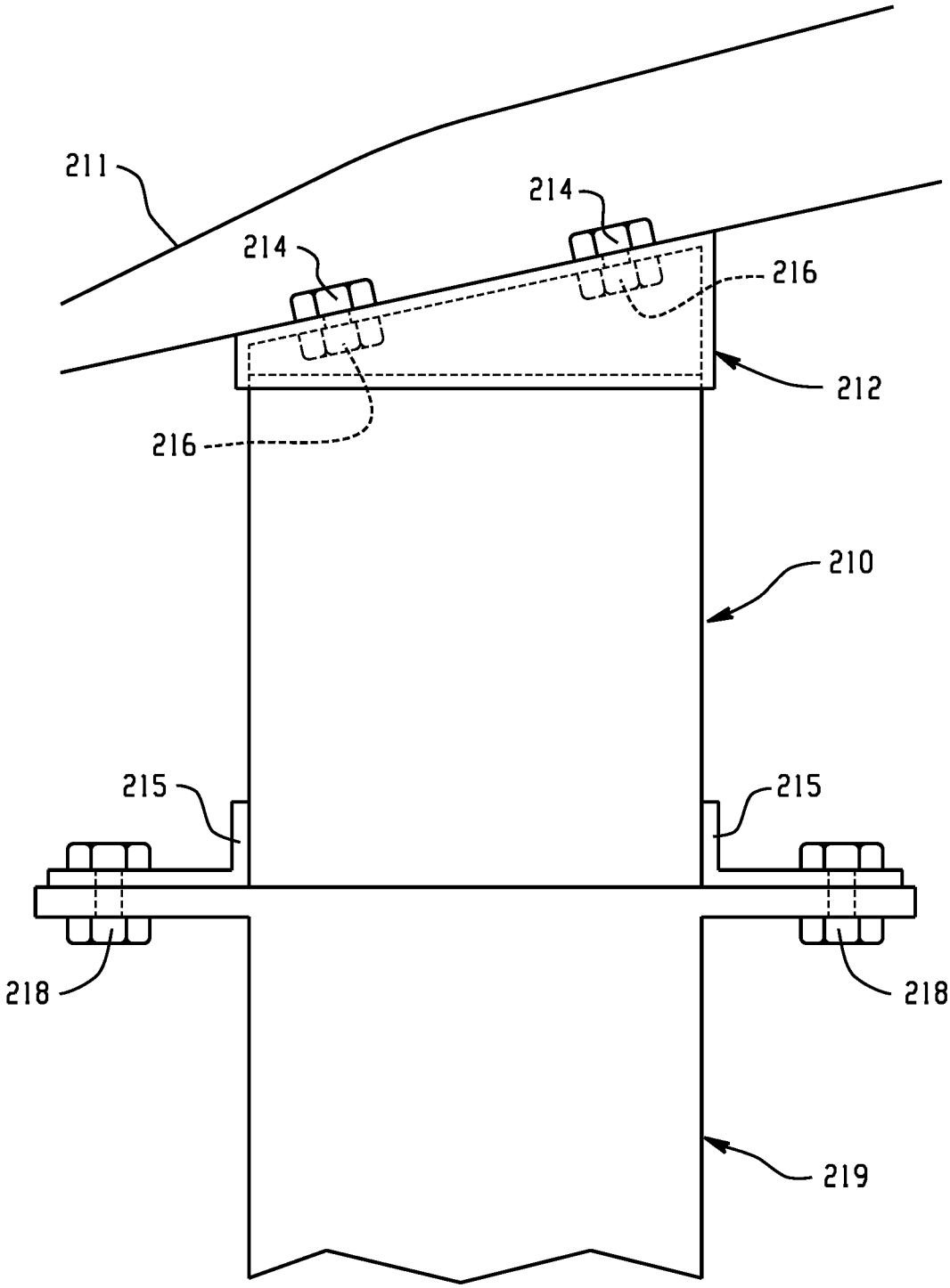


Fig. 5

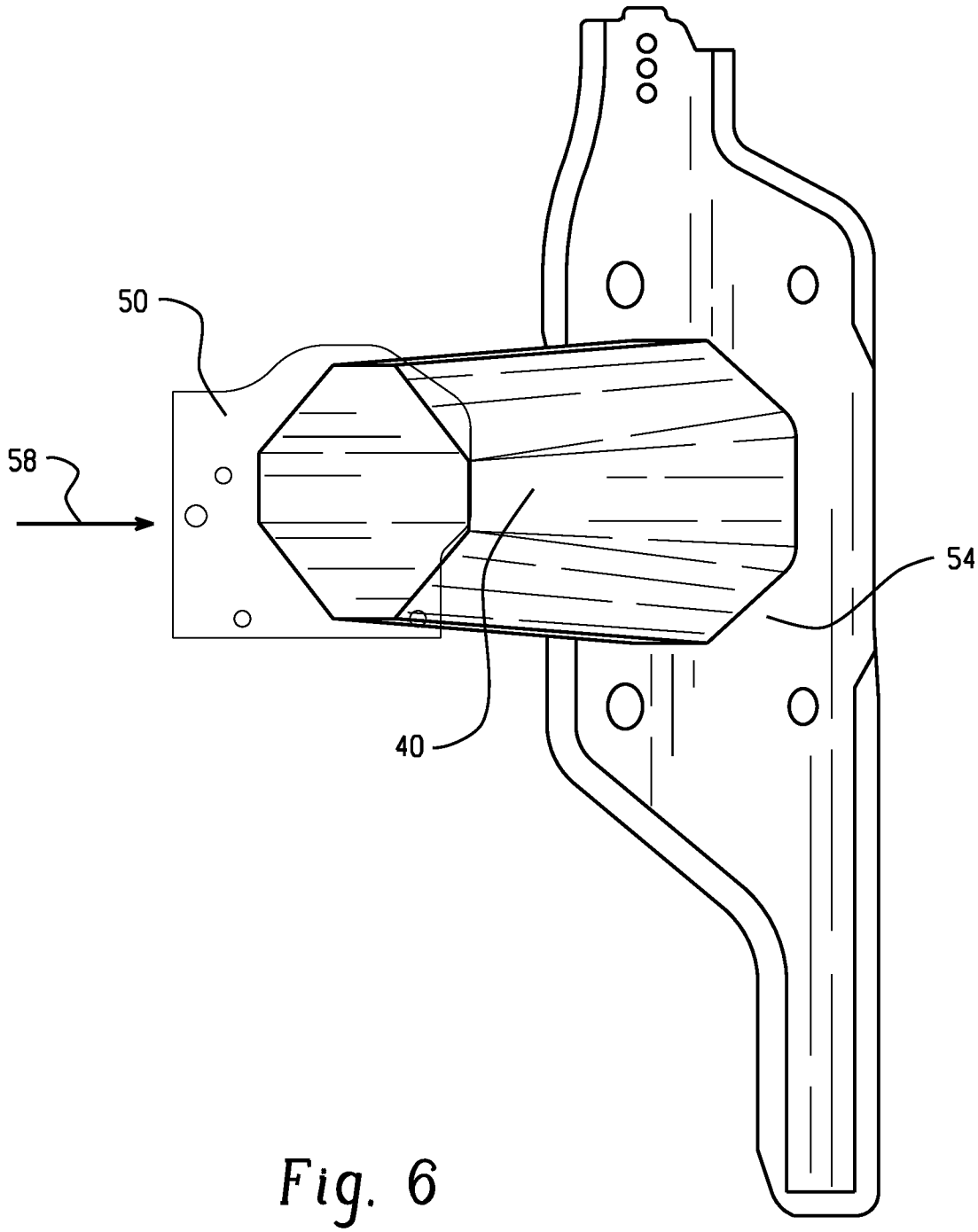


Fig. 6

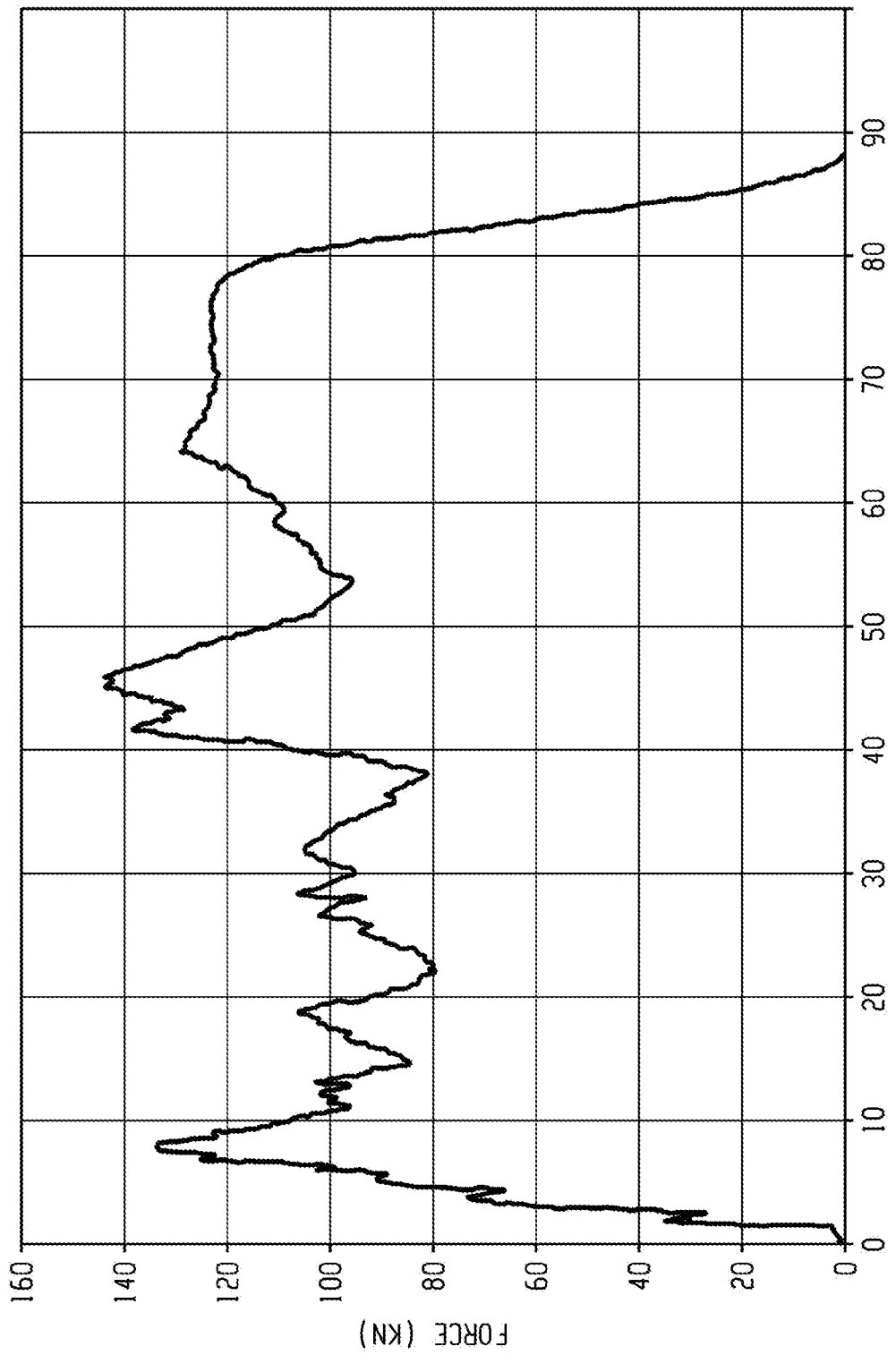

FORCE (KN)
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
TIME (mSEC)

Fig. 7

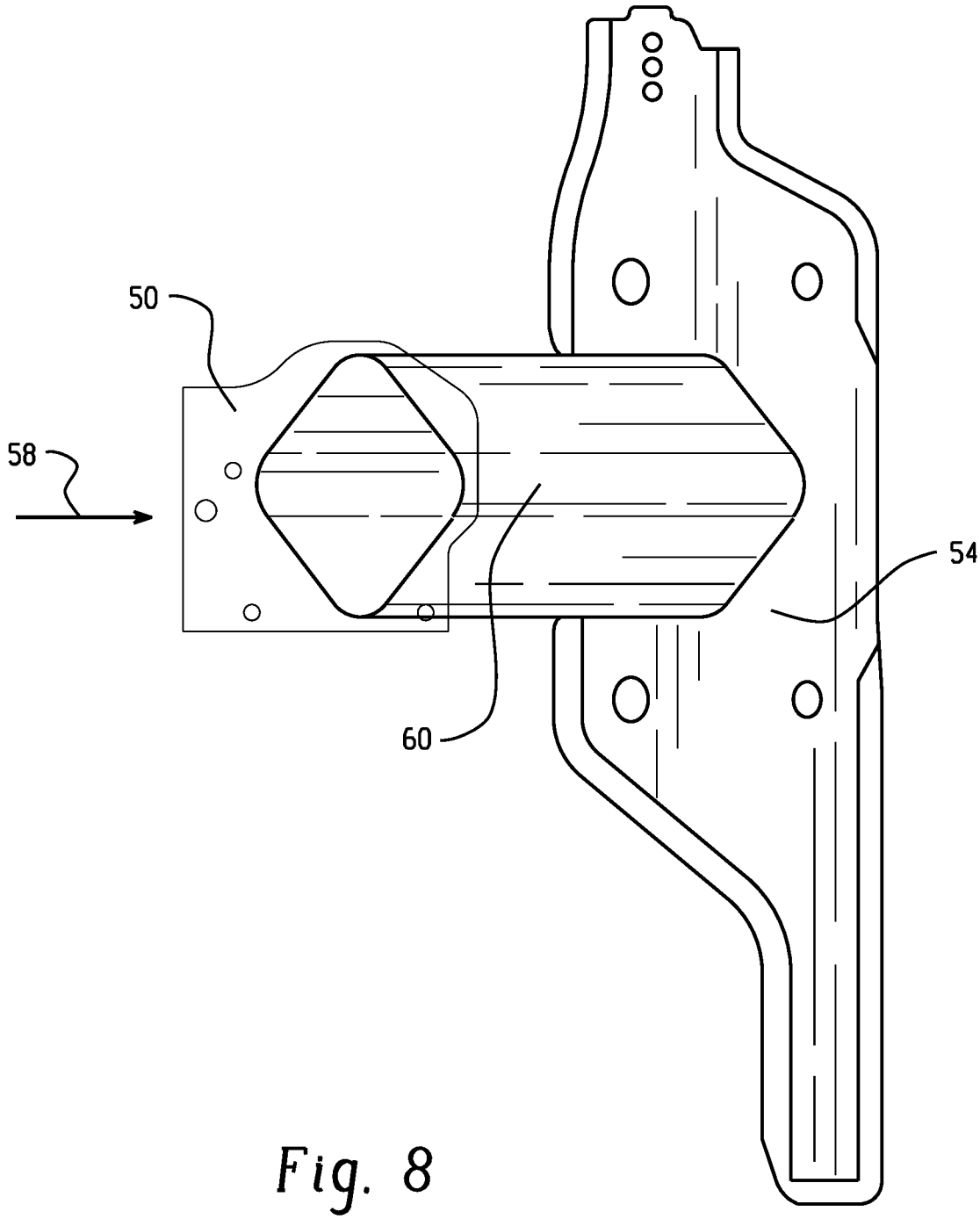


Fig. 8

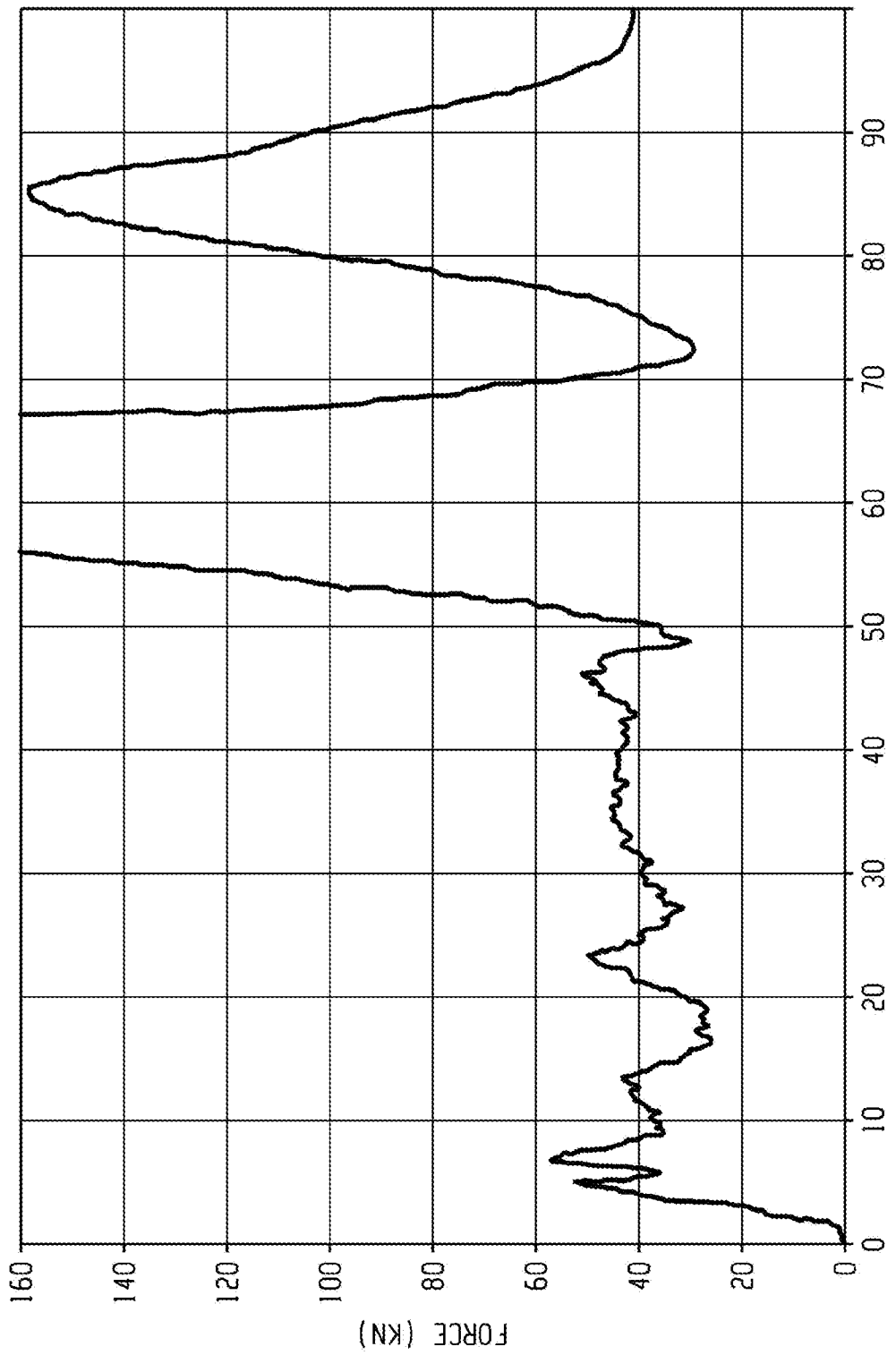

FORCE (KN)
160
140
120
100
80
60
40
20
0
TIME (mSEC)
0
10
20
30
40
50
60
70
80
90

Fig. 9

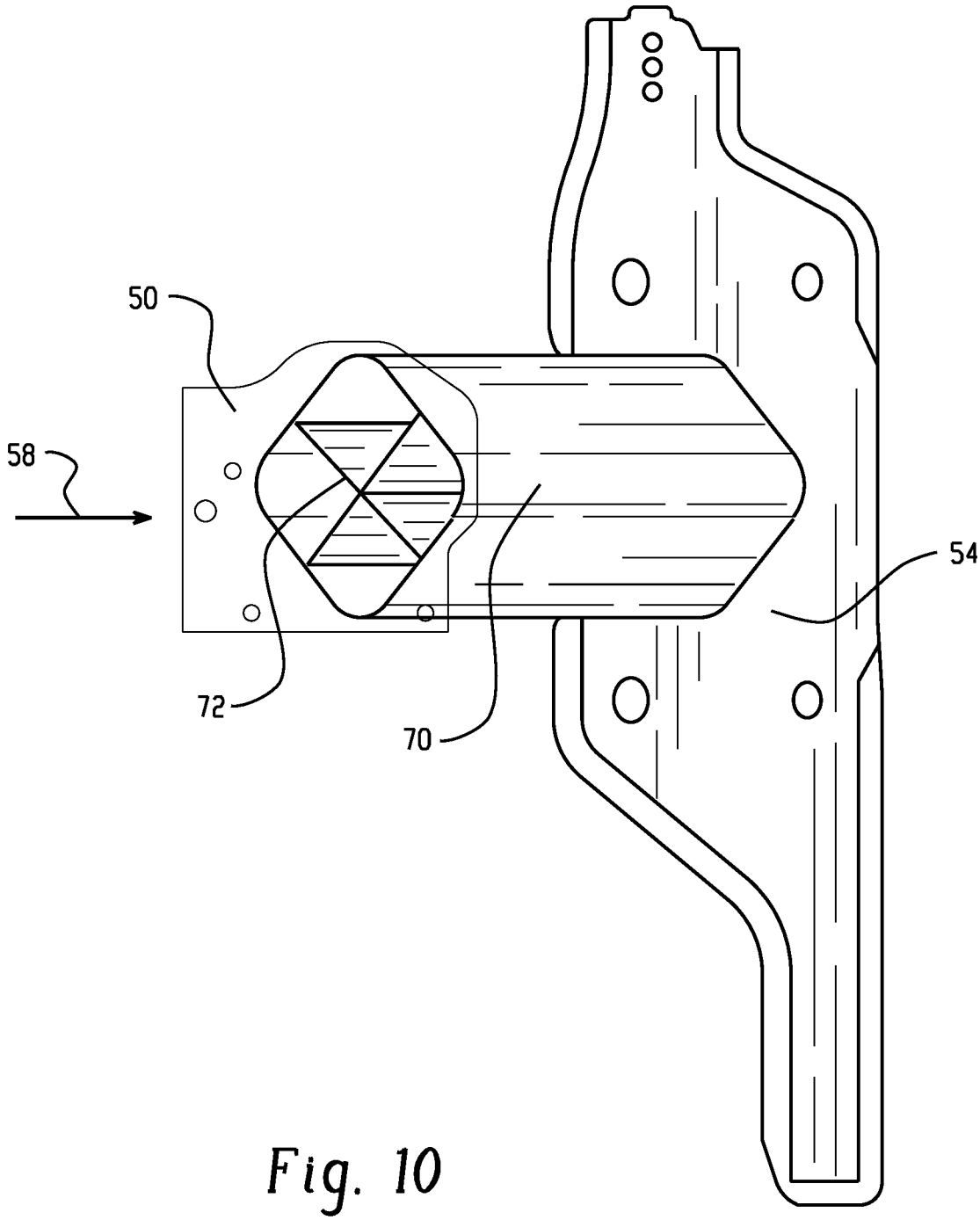


Fig. 10

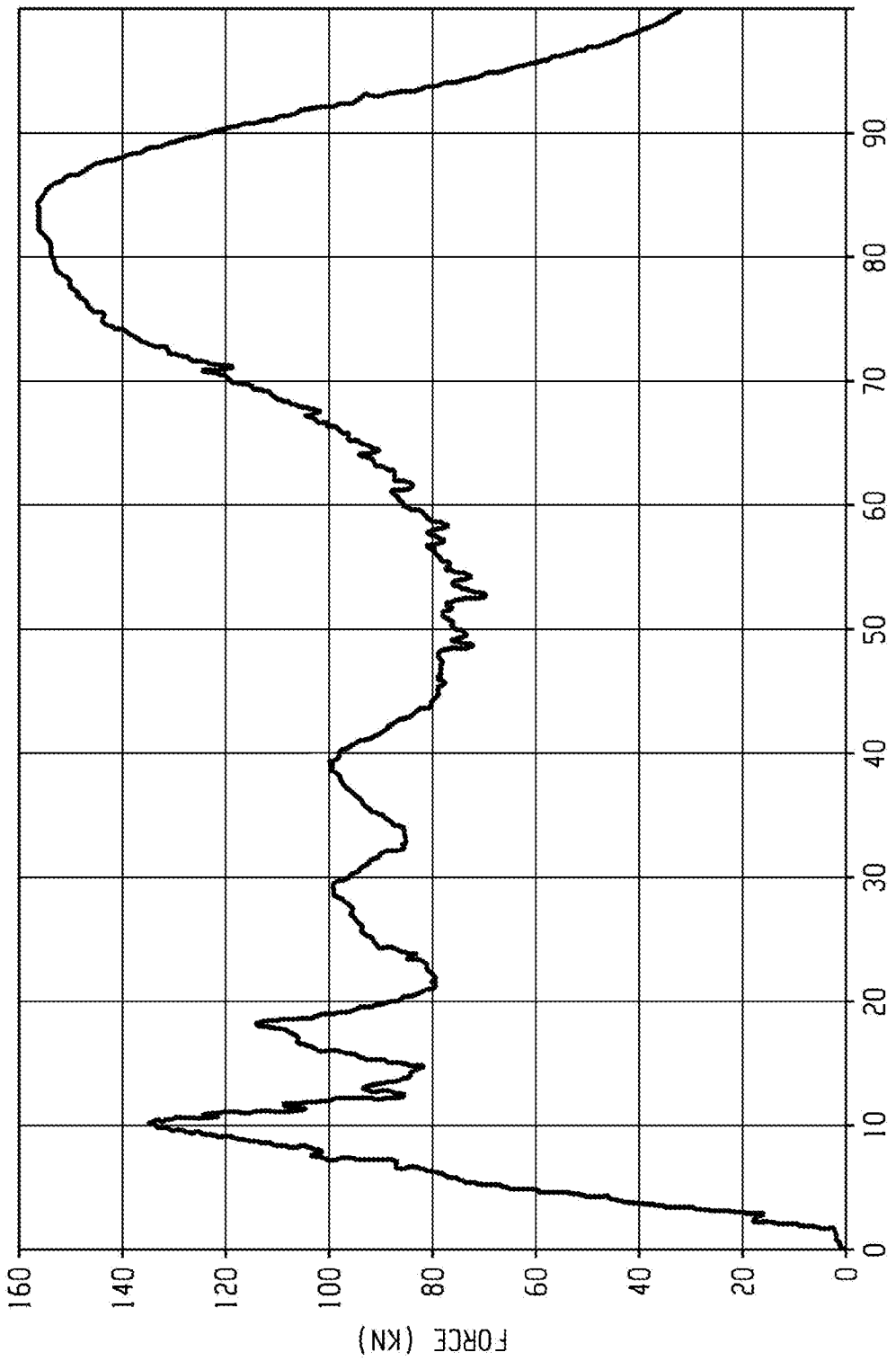

FORCE (KN)
160
140
120
100
80
60
40
20
0
TIME (mSEC)
0
10
20
30
40
50
60
70
80
90

Fig. 11

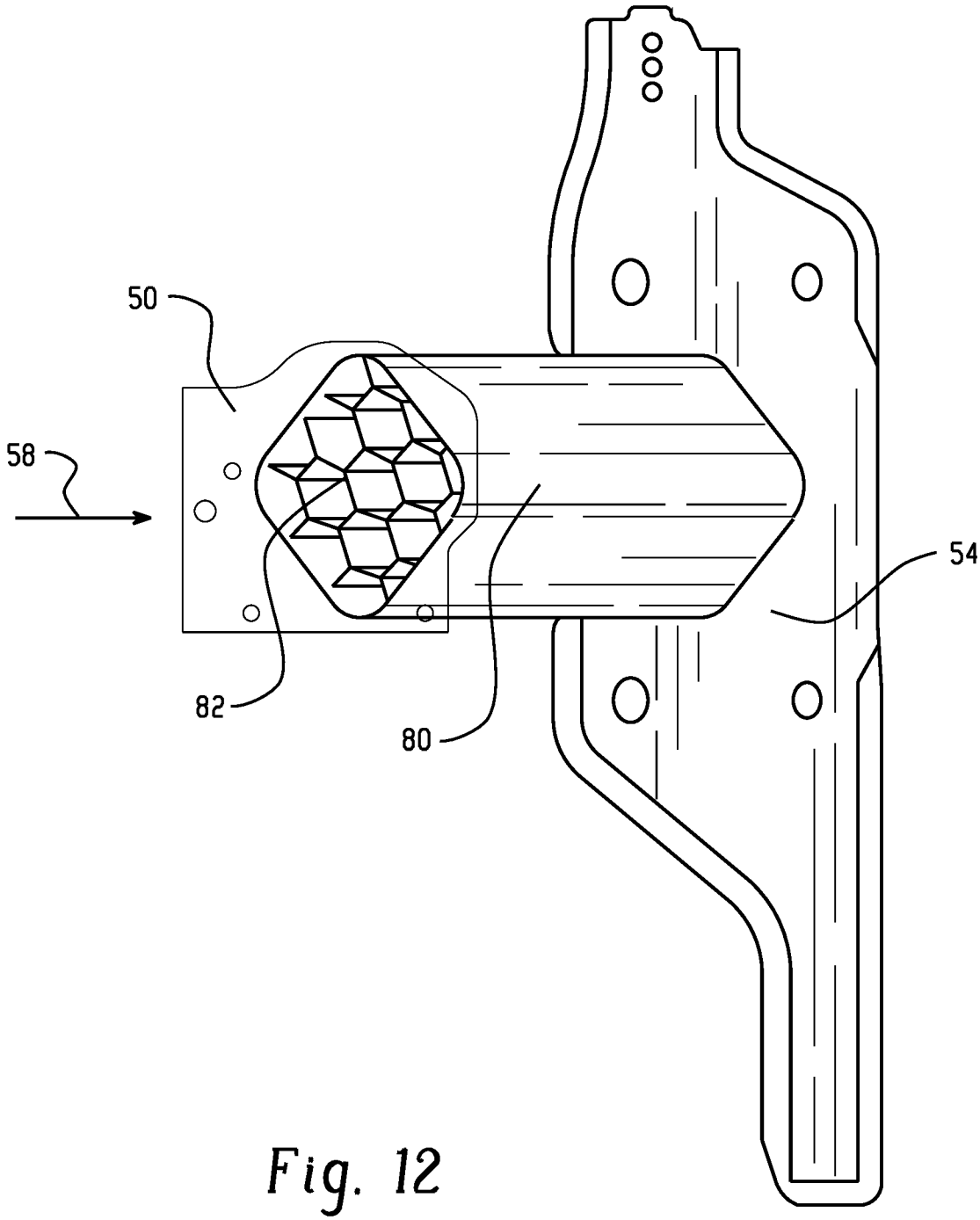


Fig. 12

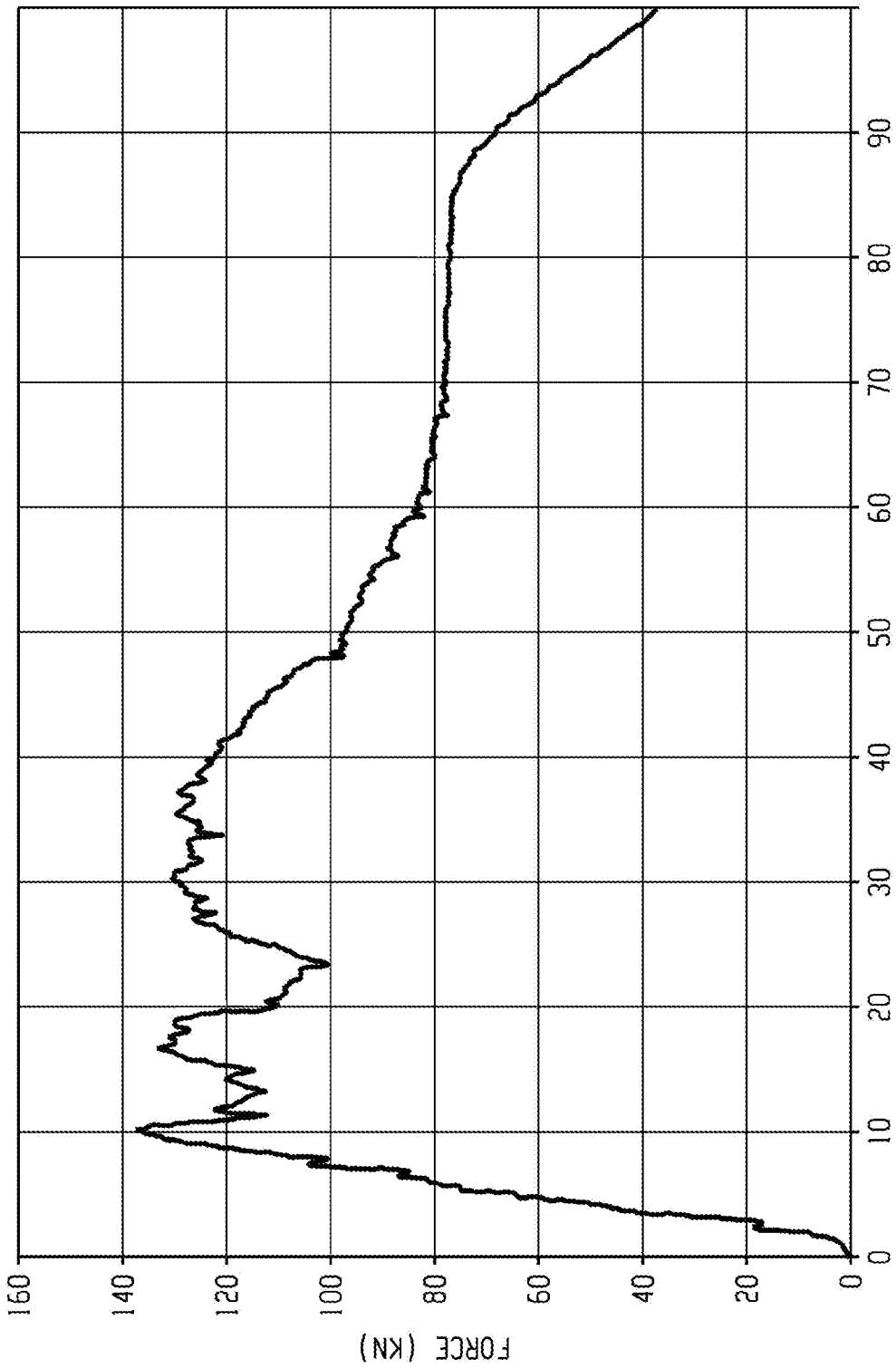

FORCE (KN)
0
20
40
60
80
100
120
140
160
TIME (mSEC)
0
10
20
30
40
50
60
70
80
90

Fig. 13

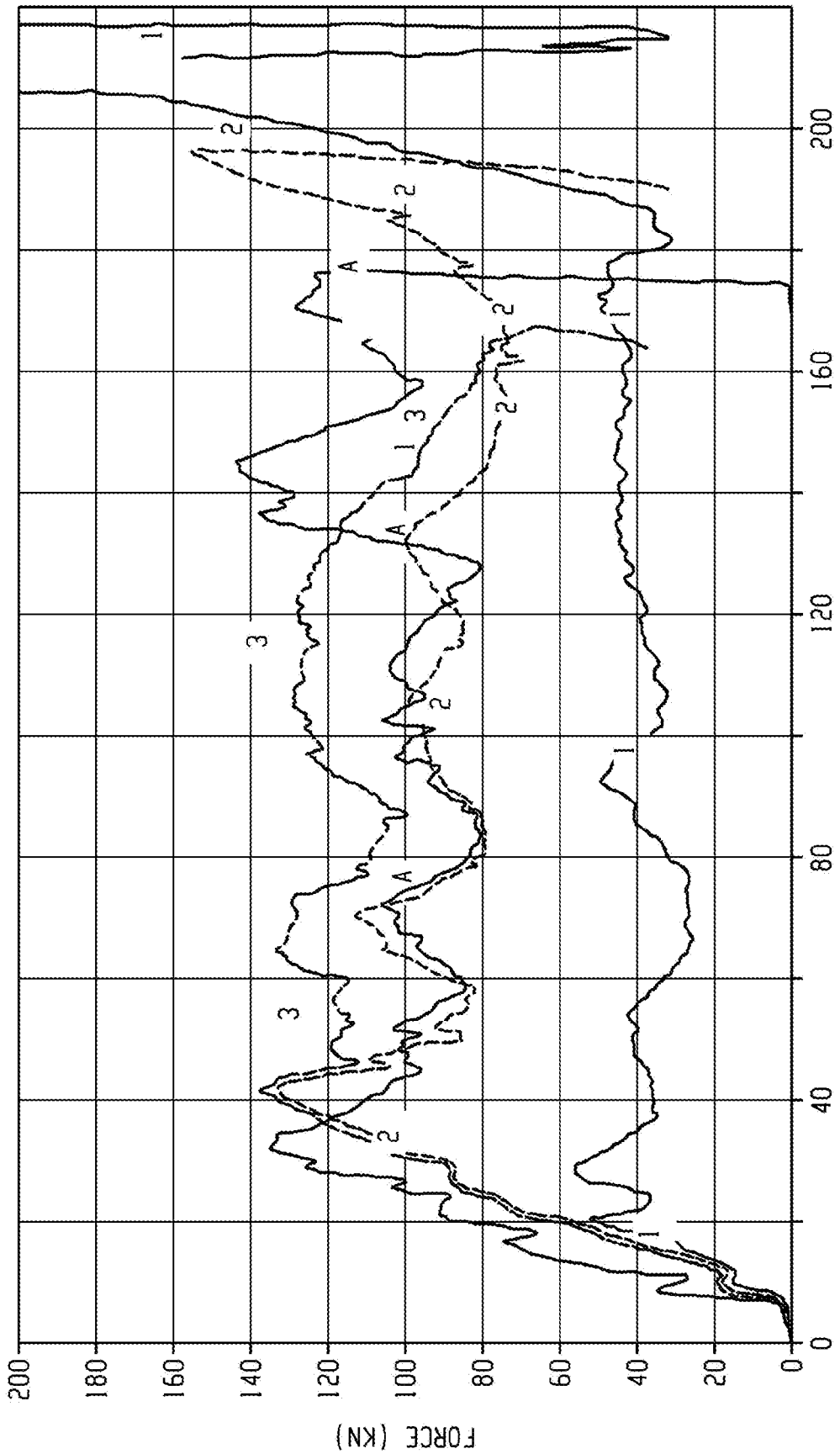

FORCE (KN)
0
20
40
60
80
100
120
140
160
180
200
DISPLACEMENT (mm)
0
40
80
120
160
200
1
2
3
A

Fig. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2018/053990

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60R19/03 B64C25/00 B60R19/34 F16F7/12
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B60R B64C F16F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2016/035694 A1 (TOYOTA JIDOSHOKKI KK [JP]) 10 March 2016 (2016-03-10) paragraph [0028] - paragraph [0048]; figures 1-3 & EP 3 190 307 A1 (KK TOYOTA JIDOSHOKKI [JP]) 12 July 2017 (2017-07-12)	1-20
X	EP 3 104 036 A1 (TEIJIN LTD [JP]) 14 December 2016 (2016-12-14) paragraph [0078] - paragraph [0096]; figures 14-20	1-20
X	EP 2 786 903 A1 (TOYOTA AUTO BODY CO LTD [JP]) 8 October 2014 (2014-10-08) paragraph [0008] - paragraph [0012]; figures 1-3	1-20

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 September 2018	27/09/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Topolski, Jan

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2018/053990

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2016/176319 A1 (SABIC GLOBAL TECHNOLOGIES BV [NL]; DELANEY MATTHEW M [US]) 3 November 2016 (2016-11-03) figures 6-7	5

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2018/053990

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2016035694 A1	10-03-2016	CN 106605079 A	26-04-2017
		EP 3190307 A1	12-07-2017
		JP 5962724 B2	03-08-2016
		JP 2016053405 A	14-04-2016
		US 2017282824 A1	05-10-2017
		WO 2016035694 A1	10-03-2016
EP 3104036 A1	14-12-2016	EP 3104036 A1	14-12-2016
		US 2016356334 A1	08-12-2016
		WO 2015119206 A1	13-08-2015
EP 2786903 A1	08-10-2014	EP 2786903 A1	08-10-2014
		US 2014305757 A1	16-10-2014
		WO 2013080863 A1	06-06-2013
WO 2016176319 A1	03-11-2016	CN 107667037 A	06-02-2018
		EP 3288801 A1	07-03-2018
		WO 2016176319 A1	03-11-2016