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Vehicle frame with integral impact mitigation features

Abstract

Systems and methods are presented herein for a vehicle frame comprising a first rail member and a second rail member. Each of the first rail member and the second rail member comprise a front rail portion, wherein the front rail portion is configured to provide resistance to deformation to protect a battery pack assembly positioned between the first rail member and the second rail member. Additionally, each of the first rail member and the second rail member comprise a rail portion, wherein the rail portion is structured to mechanically deform when subjected to a threshold impact force.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims the benefit of U.S. Provisional Patent Application No. 63/226,894 filed Jul. 29, 2021, the disclosure of which is hereby incorporated by reference herein in its entirety.

INTRODUCTION

(1) The present disclosure is directed to a vehicle frame with integrated impact mitigation features, and, more particularly a vehicle frame structured to mitigate, absorb, or deflect the force of certain

impacts (“impact mitigation”) caused by objects approaching the vehicle frame from the rear without the use of additional subassemblies fixedly attached to the vehicle frame.

SUMMARY

(2) Vehicles may have certain impact mitigation requirements and comprise frames consisting of various components structured to deform in a manner which mitigates the damage to the occupant compartment and systems of the vehicle (e.g., powertrain, steering, and vehicle occupant protection systems). A vehicle frame structured to perform impact mitigation without the use of additional subassemblies fixedly attached to the frame would be advantageous to allow the vehicle frame to be utilized without requiring significant modification while also saving on the number of components and weight of the vehicle. A rear portion of a vehicle frame with integrated impact mitigation features would prove useful towards achieving such a vehicle design.

(3) Described herein is a rear portion of a vehicle frame comprised of forward segments of material structured to withstand certain impact force values without structurally deforming and rearward segments of material structured to mechanically deform when experiencing impacts exceeding the certain force values. The integral rear portion is advantageous in that there are no weak points or stress points created by the addition of mounting features to enable an impact mitigation feature or crash assembly to be fixedly attached to the rest of the frame. The integral rear portion also reduces weight and assembly complexity as compared to frames that have a fixedly attached impact mitigation feature or crash assembly instead of the integral rear portion.

(4) The integral rear portion may comprise a plurality of welded formed panels which, when arranged in an assembled position, form a rounded quadrilateral. The integral rear portion may comprise a plurality of un-isolated mounting features to enable a vehicle body, at least one vehicle subframe, suspension components, and various components of a vehicle chassis (e.g., upper body) to be rigidly mounted to the integral rear portion. The impact force values and deformation criteria the integral rear portion is structured to comply with may be based on, at least in part, the requirements found in performance criteria for a particular product. The various features, portions, and components of the integral rear portion may include combinations of crash tubes, bend initiators, grooves, cut outs, and reinforcements enabling the integral rear portion to mechanically deform without contacting a battery module or other powertrain component accommodated by the structure of the overall vehicle frame.

(5) In some embodiments, the rear portion of a vehicle frame may comprise the integral rear portion, which may comprise two rails comprised of a plurality of frame portions structured out of segments of materials of varying thicknesses, and one or more crossmembers. A rearmost crossmember may comprise at least one attachment or mounting feature for a tow apparatus that is structured to mechanically deform along a particular trajectory when impacted by a force such as a force defined by performance criteria employed for a product comprising the subject matter of the disclosure. The rear portion may further comprise a spare wheel mounting apparatus, positioned between the two rails, that is also structured to mechanically deform along a particular trajectory when impacted by a force such as a force defined by performance criteria employed for a product comprising the subject matter of the disclosure.

(6) In some embodiments, a vehicle frame rail comprises a first rail portion comprising segments of a first thickness. Additionally, the vehicle frame rail comprises a second rail portion, attached to the first rail portion, comprising segments of a second thickness smaller than the first thickness. The vehicle frame rail further comprises a third rail portion, attached to the second rail portion, comprising segments of a third thickness smaller than the second thickness, wherein the third rail portion comprises a rear end of the vehicle frame rail. Each rail portion comprises at least two segments that partially overlap.

(7) In some embodiments, segments of adjacent rail portions of the vehicle frame rail are welded to each other, which forms a seam between the adjacent rail portions. The welded segments between each adjacent rail portion, and thus the corresponding seam, comprise an offset. Additionally, the

third rail portion comprises a height profile that decreases along a portion of its length toward the rear end.

(8) In some embodiments, the third rail portion comprises a rigid body mount. The third rail portion comprises a rigid mount configured to be attached to a crossmember that comprises a tow mount for attaching to a towing apparatus. In some embodiments, the third rail portion comprises a frame rail reinforcement positioned adjacent to an inner surface of one or more segments. In some embodiments, the frame rail reinforcement comprises a plurality of deformation initiation features comprises at least one of a cutout or a crease. Additionally, the second rail portion comprises a plurality of suspension component mounts.

(9) In some embodiments, the vehicle frame rail comprises a first rail portion comprising a first resistance to deformation. Attached to the first rail portion is a second rail portion comprising a second resistance to deformation smaller than the first resistance to deformation. Attached to the second rail portion is a third rail portion comprising a third resistance to deformation smaller than the second resistance to deformation. For example, each rail portion may initially experience a compression force in response to an impact from a rear approaching object. Additionally, individual surfaces of each rail portion may experience a tensile strain in response to the compression force and material reactions (e.g., elastic deformation) to the compression force.

(10) In some embodiments, the disclosure is directed to a vehicle frame comprising a first rail member and a second rail member. Each of the first and second rail members comprise a front rail portion, wherein the front rail portion is configured to provide resistance to deformation to protect a battery pack assembly positioned between the first rail member and the second rail member. Each of the first and second rail members comprise a rail portion, wherein the rail portion is structured to mechanically deform when subjected to a threshold impact force.

(11) In some embodiments, a rear tow mount apparatus is fixedly attached to at least a rear most crossmember of a plurality of crossmembers connected to each of the first and second rail members, and wherein the rear tow apparatus is positioned such that a rear approaching impacting object would contact the rear tow apparatus before any other feature of the vehicle frame.

(12) In some embodiments, a spare wheel mount is fixedly attached to at least one of a plurality of crossmembers connected to each of the first and second rail members, and the spare wheel mount is further structured to mechanically deform such that when a rear most crossmember feature is impacted by a rear approaching object the spare wheel mount does not make contact with a crossmember positioned in front of the spare wheel mount.

(13) In some embodiments, each of the first rail member and second rail member comprise a respective plurality of segments of varying thicknesses and wherein each of the respective plurality of segments comprise at least three different thicknesses, wherein a forwardmost segment of each of the respective plurality of segments comprises a thickest profile of the three different thicknesses. A rearmost segment of the respective plurality of segments comprises a thinnest material of the three different thicknesses. In some embodiments, at least one segment of each of the respective plurality of segments comprises a material different from the other segments of each of the respective plurality of segments.

(14) In some embodiments, each of a rear respective plurality of segments, comprising each of the rail portions, comprises features to enable deformation when a tow mount to attach a tow apparatus is impacted by a rear approaching object. In some embodiments, the first rail member comprises at least one of an internal or an external reinforcement affixed to at least one segment comprising the first rail member, wherein the at least one internal or external reinforcement increases resistance to deformation of the first rail member by increasing a thickness of the first rail member. In some embodiments, the second rail member comprises at least one of an internal or an external reinforcement affixed to at least one segment comprising the second rail member, wherein the at least one internal or external reinforcement increases resistance to deformation of the second rail member by increasing a thickness of the second rail member.

(15) In some embodiments, each of a plurality of components of the vehicle frame comprises features to enable deformation when a mount to attach a tow apparatus is impacted by a rear approaching object except for a respective front plurality of segments comprising each front rail portion.

(16) In some embodiments, at least a pair of a respective plurality of segments comprising at least a sub-portion of either the front rail portion or the rail portion is fixedly attached to each other by welding (e.g., by laser welding or other suitable welding techniques suitable for affixing the material comprising the segments together). Each of the first rail member and the second rail member comprise at least one rigid body mount and/or at least one rigid suspension mount.

(17) In some embodiments, a rearmost rigid body mount comprises a structure configured such that a vehicle body translates or deforms independent of the crossmembers and rail members when a rear crossmember, fixedly attached to each of the first rail member and the second rail member is impacted by a rear approaching object.

Description

BRIEF DESCRIPTIONS OF THE DRAWINGS

(1) The above and other objects and advantages of the disclosure may be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which:

(2) FIG. 1 depicts a frame comprising portions of varying thicknesses, in accordance with some embodiments of the disclosure;

(3) FIG. 2 depicts a frame comprising a pair of rails, in accordance with some embodiments of the disclosure;

(4) FIGS. 3A and 3B depict side views of frame rails, in accordance with some embodiments of the disclosure;

(5) FIGS. 4A and 4B depict a side view and a top view, respectively, of an exemplary crash scenario, in accordance with some embodiments of the disclosure;

(6) FIGS. 5A and 5B depict a pair of views of a deformed spare wheel mount of the frame, in accordance with some embodiments of the disclosure;

(7) FIG. 6 depicts deformation initiation features of the spare wheel mount of the frame, in accordance with some embodiments of the disclosure;

(8) FIGS. 7A and 7B depict frame rail reinforcements, in accordance with some embodiments of the disclosure; and

(9) FIG. 8 depicts three illustrative stress-strain curves of different portions of an exemplary frame rail, in accordance with some embodiments of the disclosure.

DETAILED DESCRIPTION

(10) Methods and systems are provided herein for a vehicle frame with integrated impact mitigation features structured to achieve a performance criteria associated with impacts caused by objects approaching the vehicle frame from the rear without requiring additional subassemblies to be fixedly attached to the vehicle frame.

(11) FIG. 1 is a top view of frame **100** comprised of rail portions **102**, **104**, and **106**, in accordance with some embodiments of the disclosure. Frame **100** may comprise more or fewer than the elements depicted in or described in reference to FIG. 1. Additionally, frame **100** may incorporate or may be incorporated into any or all of FIGS. 2-8.

(12) Frame **100** comprises a perimeter defined by frame rails **108A** and **108B**. Frame rails **108A** and **108B** are connected by crossmembers **110A-110D**. Each of frame rails **108A** and **108B** is comprised of rail portions **102**, **104**, and **106**, respectively. Rail portions **104** and **106**, taken together, comprise deformable frame rail portion **114**. Panels or segments that form each of rail

portions **102**, **104**, and **106** may be of varying thicknesses, lengths, and geometries. For example, frame rails **108A** and **108B** may comprise rail portions of at least three thicknesses. Rail portion **102** corresponds to a frame portion of the largest material thickness and may also be considered a rigid frame portion as it is structured to withstand impact forces from a rear approaching object (e.g., resulting initially in compressive force on the rigid frame portion which may result in surfaces of the rigid frame portion experiencing tension depending on the reaction of the material comprising the rigid frame portion to the compressive force resulting from the rear approaching object impact) without mechanically deforming or at least minimally mechanically deforming to prevent contacting the shown battery pack (e.g., may be comprised of exterior rail segments that are at least 3.0 millimeters thick). Battery pack **112** may be larger or a different geometry than the battery pack shown and is arranged between frame rails **108A** and **108B**. For example, a higher capacity battery pack may extend further to the right in the view of FIG. **1** and be positioned relatively close to the frame portion of the largest material thickness (e.g., within 10-50 mm of portion **102**). Frame **100** is structured such that crossmember **110A** does not deform, in response to a rear approaching impact heading towards crossmember **110D**, in a manner that enables crossmember **110A** to contact battery pack **112**.

(13) In some embodiments, deformable frame rail portions **114** are comprised of rail portions **104** corresponding to a second largest material thickness and rail portions **106** of a lowest material thickness of all rail portions **102**, **104** and **106** (e.g., rail portions **104** may be comprised of panels of at least a 2.0 millimeter thickness, but less than a 3.0 millimeter thickness, and rail portions **106** are comprised of panels or segments of at least a 1.8 millimeter thickness, but less than a 2.0 millimeter thickness, or, alternatively, rail portions **106** are at most 1.8 millimeters thick). Spare wheel mount **116** is fixedly attached to crossmember **110C**. The mounts and features of spare wheel mount **116** are arranged and structured such that as spare wheel mount **116** deforms when subjected to a threshold impact force (e.g., equivalent to a force corresponding to a force defined by performance criteria, spare wheel mount **116** does not contact crossmember **110B**, positioned forward of spare wheel mount **116**. Crossmember **110D** is depicted as the rearmost crossmember and comprises tow mount apparatus **118** that is positioned and structured to create a first point of impact when a rear approaching impacting object creates contact with frame **100**. Tow mount apparatus **118** may be structured to deform in a manner to prevent a rear approaching impacting object from contacting a rear wheel actuating apparatus (e.g., a drivetrain or powertrain with a central rotational axis arranged, and not depicted in FIG. **1**, between crossmembers **110B** and **110D**) positioned forward of spare wheel mount **116** and accommodated by frame **100**.

(14) Rail portions **102**, **104**, and **106** each comprise at least one material surface. In some embodiments, each of rail portions **102**, **104**, and **106** comprise geometry corresponding to a quadrilateral cross section, resulting in four different material surfaces. In some embodiments, each of the material surfaces of each of rail portions **102**, **104**, and **106** comprise a same material. In some embodiments, at least two different materials comprise the material surfaces of each of rail portions **102**, **104**, and **106**. Rail portion **102** comprises a highest yield strength and a highest ultimate strength of rail portions **102**, **104**, and **106**. Rail portion **106** comprises a lowest yield strength and a lowest ultimate strength of rail portions **102**, **104**, and **106**. Rail portion **104** comprises a yield strength and an ultimate strength higher than rail portion **106** and lower than rail portion **102**. Rail portion **106** is configured to mechanically deform prior to rail portions **104** and **106** in response to an impact from a rear approaching object (e.g., as depicted in FIGS. **4A** and **4B**). Rail portion **106** mechanically deforms in response to a compressive force generated by the impact of the rear approaching object with at least one element or feature of crossmember **110D** (e.g., tow mount apparatus **118**). In some embodiments, rail portion **106** mechanically deforms or yields in response to a compressive load generated throughout rail portion **106** from the impact of the rear approaching object. Once the compressive deformation of rail portion **106** is initiated, individual surfaces of rail portion **106** may experience tensile loads based on the mechanical deformation of

rail portion **106**.

(15) Rail portion **104** comprises a material thickness such that rail portion **104** has a resistance to deformation higher than rail portion **106** and therefore is configured to mechanically deform at a load that exceeds a deformation load of rail portion **106**. For example, if the impact load received at rail portion **106** exceeds the yield strength of rail portion **104** (e.g., is large enough to exceed at least one of a yield or ultimate strength of rail portion **106** and still exceed the yield strength of rail portion **104** after rail portion **106** mechanically deforms), then rail portion **104** is subjected to strain or mechanical deformation corresponding to the transferred or undissipated impact load.

(16) In some embodiments, when an object impacts rail portion **106**, or a component affixed to rail portion **106** (e.g., tow mount apparatus **118** which may be connected to rail portion **106** via crossmember **110D**), a reactive force at a connective interface between rail portion **104** and rail portion **106** may result in a load being transferred to rail portion **104** that exceeds at least the yield strength of rail portion **104** resulting in a cumulative build up and transfer of compressive forces throughout the frame rail comprised of rail portions **104** and **106**. Rail portion **106** is structured to mechanically deform prior to rail portion **104** initiating any mechanical deformation (e.g., a yield strength of rail portion **104** is substantially similar to, equal to, or exceeds an ultimate strength of rail portion **106**). As a result, if the impact load exceeds the ultimate strength of rail portion **106** after rail portion **106** has substantially failed (e.g., mechanically deformed to a point of breaking or fracturing) and at least meets or exceeds the yield strength of rail portion **104**, then rail portion **104** is configured to mechanically compress based on the load (e.g., the material comprising rail portion **104** will yield to the transferred load and will progressively deform until the compressive load dissipates or is prevented from continuing to compile). In some embodiments, rail portion **102** is confirmed to be resistant to any deformation in response to an impact from a rear approaching object based on parameters defined by defined by performance criteria. In some embodiments, the ultimate strength of rail portion **106** is substantially similar to, equal to, or less than the yield strength of rail portion **104**. In some embodiments, the ultimate strength of rail portion **104** is substantially similar to, equal to, or less than the ultimate strength of rail portion **102**.

(17) FIG. 2 is an isometric view of frame **100**. Frame **100** may comprise more or fewer than the elements depicted in or described in reference to FIG. 2. Additionally, frame **100** may incorporate or may be incorporated into any or all of FIGS. 1 and 3-8.

(18) Frame **100** comprises frame rails **108A** and **108B** connected by crossmembers **110A-110D**. Frame rails **108A** and **108B** are structured from inner segments **202** welded (e.g., via welds **212** which may comprise laser welds or welds created or formed by any suitable apparatus or technique considering the selected material for forming the frame rails) to outer segments **204** in an overlapping and offset manner as illustrated in FIG. 2. The arrangement of inner segments **202**, outer segments **204**, and the features thereof (e.g., bends, thickness, cut-outs, protrusions) enable the structure of frame rails **108A** and **108B** to deform in compliance with designed crash criteria (e.g., as characterized by the performance criteria defined in a performance specification or the like). Rigid rail portion **206** corresponds to rail portion **102** of FIG. 1 and is structured to retain an initial shape despite experiencing an impact. Deformable rail portion **208** corresponds to deformable rail portion **114** of FIG. 1 and is structured to deform and absorb, or deform and deflect, impact energy away from rigid portion **206**. Spare wheel mount **116** is affixed crossmember **110C**. Tow mount apparatus **118** is affixed to or comprises crossmember **110D**. Rigid body mounts **210** are arranged along ends of rails **108A** and **108B**, outboard of where crossmember **110D** is fixedly attached to each of frame rails **108A** and **108B**. Rigid body mounts **210** may be structured to mechanically deform when tow mount apparatus **118** is impacted by a rear approaching object such that a body, fixedly attached to each of rigid body mounts **210**, deforms or translates separate from frame **100**.

(19) FIGS. 3A and 3B shows side views of frame rails **300A** and **300B**. Either or both of frame rails **300A** and **300B** may comprise more or fewer than the elements depicted in or described in

reference to FIGS. 3A and 3B. Additionally, either or both of frame rails **300A** and **300B** may incorporate or may be incorporated into any or all of FIGS. **1**, **2**, and **4-8**.

(20) Frame rail **300A** comprises rail portion **102**, first deformable rail portion **104**, and second deformable rail portion **106**, each of which comprises interior segments (not shown) and outer segments (corresponding to outer segments **204** in FIG. **2**). Rail portion **102** has a largest thickness (e.g., 3.0 millimeters) of rail portions **102**, **104**, and **106**. Additionally, rail portion **102** is structured to retain a same shape and position when frame rail **300A** is impacted by rear approaching object **302** (e.g., to prevent a frame comprising frame rail **300A** from deforming enough to contact a battery pack positioned forward of rail portion **102** in a vehicle assembly). First deformable rail portion **104** has a second largest thickness (e.g., 2.0 millimeters) and corresponds to rail portion **104** of FIG. **1**. Second deformable rail portion **106** has a smaller profile or thickness (e.g., 1.8 millimeters) and corresponds to portion **106** of FIG. **1**. Second deformable rail portion **106** comprises height profile **308** that decreases along at least a portion of the length of second deformable rail portion **106** from a front of second deformable rail portion **106**, adjacent to an end of first deformable rail portion **104**, toward a rear of second deformable rail portion **106**.

(21) In some embodiments, height profile **308** is structured such that the resistance to deformation of second deformable portion **106** increases from the rear to the front of second deformable portion **106** such that the rear of second deformable portion is least resistant to deformation. In some embodiment, each of rail portion **102**, first deformable rail portion **104**, and second deformable rail portion **106** comprises panels or segment arranged such that when they are welded together and/or otherwise fixedly coupled to each other, a rail formed by these rail portion comprises a height and/or thickness profile where resistance to deformation decreases towards the rear of the assembly (e.g., as a position along the profile approaches to tow mount apparatus **118** or is substantially aligned with tow mount apparatus **118**, the lower the resistance of the rail corresponding to that position is to deformation). First deformable rail portion **104** and second deformable rail portion **106** are structured to deform along a trajectory which minimizes or prevents translation or deformation of rail portion **102** when impacted by rear approaching object **302**. Frame rail **300A** also comprises suspension component mounts **310** (e.g., damper and spring mounts) as well as body-to-frame mounts **312**. Each of the mounts may be rigid and without isolation or may incorporate some aspects of isolation so long as the stiffness (e.g., as defined by at least one of the Young's Modulus of the mount, the yield strength of the mount, or the ultimate strength of the mount) and planned deformation of the overall rear frame satisfies criteria (e.g., as interpreted from performance criteria).

(22) Frame rail **300B**, corresponding to a side view of frame rail **108B** of FIG. **1**, comprises rail portion **102**, first deformable portion **104**, and second deformable portion **106**. Affixed to portion **102** are deformation resistant reinforcements **314** arranged along the underside of portion **102**. Deformation resistant reinforcements **314** may be welded to portion **102** or otherwise fixedly attached to maintain a flush connection between a surface of deformation resistant reinforcements **314** and portion **102** such that deformation resistant reinforcements **314** provide structural support to portion **102**, thereby increasing the mechanical deformation threshold of portion **102**. Deformation resistant reinforcements **314** may increase the total thickness of material arranged in portion **102** to 5.0 millimeters or more. First deformable portion **104** comprises deformation reducing reinforcements **316**, which results in a material thickness which may exceed 3.0 millimeters and does not exceed or reach 5.0 millimeters. Second deformable portion **106** comprises no reinforcements. Each of the portions with reinforcements or reinforcement panels applied may be welded or mechanically fixedly attached in a manner that creates asymmetric attachment points (e.g., the overlapping and offset joints shown in FIGS. **2** and **3**) such that any thin or weak components in the frame rail are not directly along a same axis and/or on a same plane. Additionally, frame rail **300B** comprises deformation initiation features **318**. Deformation initiation features **318** may comprise features such as mounting points, cut-outs, bends, and/or

protrusions that enable a frame comprising frame rail **300B** to meet crash criteria, as described in this disclosure (e.g., to ensure second deformable portion **106** mechanically deforms in response to rear approaching impact forces before first deformable portion **104** mechanically deforms and first deformable portion **104** deforms in response to the rear approaching impact forces before portion **102** is subjected to forces that result in mechanical deformation of portion **102**).

(23) FIG. **4A** shows side view **400A** and FIG. **4B** shows top view **400B** of vehicle rear portion **402** experiencing an impact from rear approaching object **404** about tow mount apparatus **118** affixed to crossmember **110D** connecting frame rail **108B** to a second frame rail (e.g., frame rail **108A** of FIG. **1**), in accordance with some embodiments of the disclosure. Vehicle rear portion **402** may comprise more or fewer than the elements depicted in or described in reference to FIGS. **4A** and **4B**. Additionally, vehicle rear portion **402** may incorporate or may be incorporated into any or all of FIGS. **1-3** and **5-8**.

(24) As shown via side view **400A** of FIG. **4A** and top view **400B** of FIG. **4B**, vehicle rear portion **402** is subjected to an off-center impact based on the approach trajectory of rear approaching object **404**. Tow mount apparatus **118** is arranged such that rear approaching object **404** creates single contact point **406** with tow mount apparatus **118** such that frame rail **108B** may direct and/or divert forces from the impact along predetermined deformation paths (e.g., as enabled by deformation initiation features **318** of FIG. **3** as well as the varying thicknesses of portions of frame rail **108B**, as described herein).

(25) FIG. **5A** depicts angled view **500A** and FIG. **5B** depicts top view **500B** of deformed frame **500**, where deformed frame **500** has mechanically deformed in response to being impacted by a rear approaching object (e.g., rear approaching object **404** of FIG. **4**) about tow mount apparatus **118**. Deformed frame **500** may comprise more or fewer than the elements depicted in or described in reference to FIGS. **5A** and **5B**. Additionally, deformed frame **500** may incorporate or may be incorporated into any or all of FIGS. **1-4** and **6-8**.

(26) Deformed frame **500** comprises deformed first portion **504** and deformed second portion **506**, which have deformed because of an impact by a rear approaching object (e.g., rear approaching object **404** of FIG. **4**). Deformed first portion **504** and deformed second portion **506** together correspond to deformable frame rail portions **114** of FIG. **1**, where deformed second portion **506** comprises panels and other deformation initiation features (e.g., deformation initiation features **318** of FIG. **3**) such that deformed second portion **506** experiences mechanical deformation prior to deformed first portion **504** experiencing mechanical deformation. As shown in FIG. **5**, deformed section portion **506** exhibits more mechanical deformation than deformed first portion **504**.

(27) Rigid body mount **210** is positioned towards the rear of deformed second portion **506**. Rigid body mount **210** is structured to deform relatively independent of a body fixedly attached by rigid body mount **210** to deformed frame **500**. For example, as frame **500** mechanically deforms in response to a rear approaching impact (e.g., crumples), rigid body mount **210** moves towards crossmember **110C** and downward away from the body fixedly attached at rigid body mount **210**. This separation may result in a bend to the body; however, the body is free to translate away from deformed frame **500** and may not crumple in the same manner as deformed frame **500**. Deformed spare wheel mount **502** is shown affixed to crossmember **110C**. Crossmember **110C** connects a pair of frame rails (e.g., frame rails **108A** and **108B** of FIG. **1**). Deformed spare wheel mount **502** comprises varying mount, reinforcement and deformation initiation features to enable a wheel to be secured to deformed spare wheel mount **502** prior to the rear approaching impact. These varying mount, reinforcement, and deformation initiation features are structured to limit variation in the deformation of deformed spare wheel mount **502** such that features and subcomponents of deformed frame **500** arranged to the left of outer segment **204** and inner segment **202** are not affected or deformed by the rear approaching impact.

(28) Top view **500B** of deformed frame **500** depicts deformed spare wheel mount **502** affixed to crossmember **110C**. Crossmembers **110B**, **110C**, and **110D** connect a pair of frame rails (e.g., frame

rails **108A** and **108B** of FIG. 1). As shown, deformed spare wheel mount **502** is structured to deform when the frame rails are subjected to an impact from a rear approaching object without contacting crossmember **110B**.

(29) FIG. 6 depicts partially deformed spare wheel mount **600** comprising deformation initiation features **602A-C** (e.g., cutouts and creases) structured to enable partially deformed spare wheel mount **600** to mechanically deform without contacting a crossmember positioned forward of partially deformed spare wheel mount **600** (e.g., as shown in FIG. 5). Partially deformed spare wheel mount **600** may comprise more or fewer than the elements depicted in or described in reference to FIG. 6. Additionally, partially deformed spare wheel mount **600** may incorporate or may be incorporated into any or all of FIGS. 1-5, 7, and 8.

(30) Deformation initiation feature **602A** comprises a crease along an edge of partially deformed spare wheel mount **600**. A crease decreases the stiffness (e.g., as defined by at least one of the Young's Modulus of the material, the yield strength of the material, or the ultimate strength of the material that comprises spare wheel mount **600**) in the material formed to have the crease as during formation of the crease there is intentional damage to the material structure forming the material. A strategically aligned crease (e.g., along an edge of a component configured to deform) enables intentional and strategic deformation profiles, as shown in FIG. 6. Deformation initiation feature **602B** comprises a circular cutout in the material is also used to reduce stiffness (e.g., as defined by at least one of the Young's Modulus of the material, the yield strength of the material, or the ultimate strength of the material that comprises spare wheel mount **600**) without impacting vibrational modes of the material in which the circular cutout is formed. The circular cutout concentrates material stress about deformation initiation feature **602B**, thereby initiating deformation proximate to deformation initiation feature **602B** without impacting vibrational response of the material. Deformation initiation feature **602C** comprises an oval cutout in the material forming partially deformed spare wheel mount **600**. An oval or elliptical cutout decreases the surface area of a region subjected to mechanical material stress (e.g., buckling stress or torsional stress as experienced by material subjected to an impact when affixed at various mounting points like partially deformed spare wheel mount **600**). The oval or elliptical cutout enables an increased resistance to buckling forces along the elongated sides of the cutout, thereby directing a buckling force to other portions of material with the oval or elliptical cutout. As shown in FIG. 6, deformation initiation feature **602C**, comprising the oval or elliptical shape, remains in an original shape along the elongated sides of deformation initiation feature **602C** and other portions of partially deformed spare wheel mount **600** are depicted with increase deformation with respect to the material comprising and surrounding deformation initiation feature **602C**.

(31) FIGS. 7A and 7B show a pair of views of second deformable portion **106**, comprising frame rail reinforcements **700A** and **700B**, that is arranged to be fixedly attached to a bottom surface of second deformable portion **106**. Frame rail reinforcements **700A** and **700B** may comprise more or fewer than the elements depicted in or described in reference to FIGS. 7A and 7B. Additionally, frame rail reinforcements **700A** and **700B** may incorporate or may be incorporated into any or all of FIGS. 1-6, and 8.

(32) Frame rail reinforcements **700A** and **700B** are arranged in an installation position along a bottom of second deformable portion **106** and proximate to rigid body mount **210**, which is positioned towards the rear of crossmember **110D** of FIG. 1. Also shown is an end of first deformable portion **104** and crossmember **110C**. As discussed in reference to FIGS. 1-3, first deformable portion **104** is structured to mechanically deform in response to rear approaching impacts and comprises panels or segments that are thicker than second deformable portion **106** and frame rail reinforcements **700A** and **700B** such that second deformable portion **106** and frame rail reinforcements **700A** and **700B** mechanically deform prior to first deformable portion **104** experiencing mechanical deformation. For reference, height profile **308** of FIG. 3 illustrates the curvature of a top surface of second deformable portion **106** if it were depicted in FIG. 7.

(33) Reinforcement **700B** is shown as comprising deformation initiation features **702A-D** (e.g., cutouts and creases in a main body of frame rail reinforcements **700A** and **700B** such that although reinforcement **700B** increases the resilience of second deformable portion **106**, second deformable portion **106** remains configured to mechanically deform prior to first deformable portion **104**). Deformation initiation feature **702A** comprises a circular cutout with properties akin to those of deformation initiation feature **602B** of FIG. 6. Deformation initiation feature **702B** comprises a semi-circular cutout along an edge of reinforcement **700B**, which is configured to reduce stiffness (e.g., as defined by at least one of the Young's Modulus of the material, the yield strength of the material, or the ultimate strength of the material that comprises reinforcement **700B**) along the edge of reinforcement **700B** such that reinforcement **700B** is configured to deform rotationally and proximate to deformation initiation feature **702B**. Deformation initiation feature **702C** comprises a semi-circular crease along the edge of reinforcement **700B** such that reinforcement **700B** has a reduced resistance (e.g., as defined by at least one of the Young's Modulus of the material, the yield strength of the material, or the ultimate strength of the material that comprises reinforcement **700B**) to compression forces (e.g., as caused by a rear approaching impacting object) such that reinforcement **700B** deforms along a crease comprising deformation initiation feature **702C** before deformable portion **104** is subjected to mechanical deformation. Deformation initiation feature **702D** comprises an oval or elliptical shape and corresponds to deformation initiation feature **602C** of FIG. 6.

(34) FIG. 8 depicts chart **800** populated with stress-strain curves **802A**, **802B**, and **802C**, each corresponding to different portions of an exemplary frame rail, in accordance with some embodiments of the disclosure. Each of stress-strain curves **802A**, **802B**, and **802C** correspond to frame rails that may comprise more or fewer than the elements depicted in or described in reference to FIGS. 1-8.

(35) Chart **800** comprises vertical stress axis **804** and horizontal strain axis **806**. Vertical stress axis **804** corresponds to internal forces experienced by contacting portions of material comprising a frame rail. Horizontal strain axis **806** corresponds to an amount of deformation experienced by material in response to the internal forces of vertical stress axis **804**. Vertical stress axis **804** may be scaled based on the force generated by an impact of a rear approaching object with a rear portion of a vehicle frame (e.g., as defined by or interpreted in reference to performance criteria). Each of stress-strain curves **802A-C** characterize a resistance to deformation of each of rail portions **106**, **104**, and **102**, respectively. For example, the yield and ultimate strengths of each curve correspond to values which, if exceeded, would result in at least one of elastic or plastic mechanical deformation of each of rail portions **106**, **104**, and **102**. In some embodiments, the resistance to deformation may be characterized by a slope of the depicted stress-strain curves from the start of the curve at the intersection of the depicted axes up to the depicted yield strengths, corresponding to the Young's modulus for each respective rail portion. In some embodiments, the resistance to deformation (e.g., at least one of the yield strength, the ultimate strength, and the Young's modulus) may vary along the length of each respective rail portion. The resistance to deformation for each respective rail portion may correspond to a minimum value of at least one of the yield strength, the ultimate strength, and the Young's modulus for each respective rail portion.

(36) Stress-strain curve **802A** corresponds to a response of rail portion **106** of FIG. 1 to a force corresponding to an impact from a rear approaching object (e.g., as depicted in FIGS. 4A and 4B). Stress-strain curve **802A** comprises yield strength **804A** and ultimate strength **806A** of rail portion **106**. Ultimate strength **806A** is substantially similar to, equal to, or less than yield strength **804B** of stress-strain curve **802B**. Stress-strain curve **802B** corresponds to a response of rail portion **104** of FIG. 1 to a force corresponding to an impact from a rear approaching object (e.g., as depicted in FIGS. 4A and 4B). Stress-strain curve **802B** comprises yield strength **804B** and ultimate strength **806B** of rail portion **104**. Ultimate strength **806B** is substantially similar to, equal to, or less than yield strength **804C** of stress-strain curve **802C**. Stress-strain curve **802C** corresponds to a response

of rail portion **102** of FIG. **1** to a force corresponding to an impact from a rear approaching object (e.g., as depicted in FIGS. **4A** and **4B**). Stress-strain curve **802C** comprises yield strength **804C** and ultimate strength **806C** of rail portion **102**. Ultimate strength **806C** is substantially similar to or greater than an ultimate force corresponding to an impact from a rear approaching object as defined by or interpreted from performance criteria. Each of the strengths depicted correspond to a resistance to compressive or tensile deformation of each of rail portions **102**, **104**, and **106**. In some embodiments, these curves may be adjusted depending on the integration of deformation initiation features (e.g., as shown in and described in reference to FIGS. **7A** and **7B**) in each of rail portions **102**, **104**, and **106**.

(37) The systems and processes discussed above are intended to be illustrative and not limiting. One skilled in the art would appreciate that the actions of the processes discussed herein may be omitted, modified, combined, and/or rearranged, and any additional actions may be performed without departing from the scope of the invention. More generally, the above disclosure is meant to be exemplary and not limiting. Only the claims that follow are meant to set bounds as to what the present disclosure includes. Furthermore, it should be noted that the features and limitations described in any one embodiment may be applied to any other embodiment herein, and flowcharts or examples relating to one embodiment may be combined with any other embodiment in a suitable manner, done in different orders, or done in parallel. In addition, the systems and methods described herein may be performed in real time. It should also be noted that the systems and/or methods described above may be applied to, or used in accordance with, other systems and/or methods.

(38) While some portions of this disclosure may refer to examples, any such reference is merely to provide context to the instant disclosure and does not form any admission as to what constitutes the state of the art.

Claims

1. A vehicle frame rail comprising: a first rail portion comprising segments of a first thickness; a second rail portion, attached to the first rail portion, comprising segments of a second thickness smaller than the first thickness; and a third rail portion, attached to the second rail portion, comprising segments of a third thickness smaller than the second thickness, wherein: the third rail portion comprises a rear end of the vehicle frame rail and a frame rail reinforcement positioned adjacent to an inner surface of one or more segments of the third rail portion, and the frame rail reinforcement comprises a plurality of deformation initiation features comprising at least one of a cutout or a crease.
2. The vehicle frame rail of claim 1, wherein each of the first, the second and the third rail portion comprises at least two segments that partially overlap.
3. The vehicle frame rail of claim 2, wherein two segments of adjacent rail portions of the vehicle frame rail that partially overlap are welded to each other, which forms a seam between the adjacent rail portions.
4. The vehicle frame rail of claim 3, wherein the two segments welded to each other between each adjacent rail portion, and thus the corresponding seam, comprise an offset.
5. The vehicle frame rail of claim 1, wherein the third rail portion comprises a height profile that decreases along a portion of its length toward the rear end.
6. The vehicle frame rail of claim 1, wherein the third rail portion comprises a rigid body mount.
7. The vehicle frame rail of claim 1, wherein the third rail portion comprises a rigid mount configured to be attached to a crossmember that comprises a tow mount for attaching to a towing apparatus.
8. The vehicle frame rail of claim 1, wherein the second rail portion comprises a plurality of suspension component mounts.

9. A vehicle frame rail comprising: a first rail portion comprising a first resistance to deformation; a second rail portion, attached to the first rail portion, comprising a second resistance to deformation smaller than the first resistance to deformation; and a third rail portion, attached to the second rail portion, comprising a third resistance to deformation smaller than the second resistance to deformation, wherein: the third rail portion comprises a rear end of the vehicle frame rail and a frame rail reinforcement positioned adjacent to an inner surface of one or more segments of the third rail portion, and the frame rail reinforcement comprises a plurality of deformation initiation features comprising at least one of a cutout or a crease.

10. A vehicle frame comprising: a first rail member and a second rail member, each comprising: a respective front rail portion, wherein the front rail portion is configured to provide resistance to deformation to protect a battery pack assembly positioned between the first rail member and the second rail member; a respective middle rail portion affixed to the front rail portion; and a respective rear rail portion affixed to the respective middle rail portion and structured to mechanically deform when subjected to a threshold impact force, wherein: the respective rear rail portion comprises a respective rear end of a respective vehicle frame rail and a respective frame rail reinforcement positioned adjacent to an inner surface of one or more segments of the rear rail portion, and the respective frame rail reinforcement comprises a respective plurality of deformation initiation features comprising at least one of a cutout or a crease.

11. The vehicle frame of claim 10, wherein a rear tow mount apparatus is fixedly attached to at least a rear most crossmember of a plurality of crossmembers connected to each of the first and second rail members, and wherein the rear tow apparatus is positioned such that a rear approaching impacting object would contact the rear tow apparatus before any other feature of the vehicle frame.

12. The vehicle frame of claim 10, wherein a spare wheel mount is fixedly attached to at least one of a plurality of crossmembers connected to each of the first and second rail members, and the spare wheel mount is further structured to mechanically deform such that when a rearmost crossmember feature is impacted by a rear approaching object, the spare wheel mount does not contact a crossmember positioned in front of the spare wheel mount.

13. The vehicle frame of claim 10, wherein each of the first rail member and second rail member comprises a respective plurality of segments of varying thicknesses and wherein each of the respective plurality of segments comprise at least three different thicknesses, wherein a forwardmost segment of each of the respective plurality of segments comprises a thickest profile of the three different thicknesses.

14. The vehicle frame of claim 13, wherein a rearmost segment of each of the respective plurality of segments comprises a thinnest profile of the three different thicknesses.

15. The vehicle frame of claim 14, wherein at least one segment of each of the respective plurality of segments comprises a material different from other segments of each of the respective plurality of segments.

16. The vehicle frame of claim 10, wherein each of the first rail member and second rail member comprises a respective plurality of segments that collectively form the front rail portion, the middle rail portion, and the rear rail portion, and wherein each segment of the respective plurality of segments comprises at least one feature to enable deformation when a tow mount apparatus is impacted by a rear approaching object.

17. The vehicle frame of claim 10, wherein: the respective frame rail reinforcement of the respective rear rail portion of the first rail member is affixed to at least one internal or external surface of a respective segment comprising the first rail member, wherein the respective frame rail reinforcement of the respective rear rail portion of the first rail member increases resistance to deformation of the first rail member by increasing a thickness of the first rail member; and the respective frame rail reinforcement of the respective rear rail portion of the second rail member is affixed to at least one internal or external surface of a respective segment comprising the second

rail member, wherein the respective frame rail reinforcement of the respective rear rail portion of the second rail member increases resistance to deformation of the second rail member by increasing a thickness of the second rail member.

18. The vehicle frame of claim 10, wherein each of the respective middle rail portions comprise respective features to enable deformation when a mount to attach a tow apparatus is impacted by a rear approaching object.
